

Biodiversity of Indian Rotifers (Rotifera) with remarks on biogeography and richness in diverse ecosystems

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Abstract. We assess biodiversity status of Rotifera known from India to-date based on our studies from various regions of this country and evaluation of other viable records, and highlight notable features of biogeography and richness. The Indian fauna reveals 434 valid species belonging to 68 genera and 25 families and thus indicates the most biodiverse Rotifera vis-à-vis south and Southeast Asia, and records ~25% and ~41% species of global and regional biogeographic interest. It depicts the littoral-periphytic nature, broadly tropical character, the limited reports of cold-water species from the sub-Himalayan and Himalayan latitudes, paucity of the endemics and Bdelloids, and cryptic diversity awaits analyses. The richest diversity and distinct biogeographic identity of Rotifera of Northeast India (NEI) is attributed to location of this region in the 'Himalayan and Indo-Burmese' biodiversity hot-spots, 'Assam gateway' – the biogeographic corridor, and the 'Rotiferologist effect'. Regional disparity and spatial heterogeneity of biodiversity elsewhere from India are attributed to the limited sampling, inadequate collections from diverse ecosystems, unidentified species, and paucity of attention on smaller species. The biodiverse rotifer assemblages of the floodplain lakes including Deepor Beel and Loktak Lake, the two Ramsar sites and globally megadiverse ecosystems, are hypothesized to habitat diversity of these ecotones, while 'Rotifera paradox' depict speciose constellations per sample. The species-rich small floodplain and urban wetlands focus interest on rotifer diversity in small water bodies. We estimate more diverse Indian Rotifera following analyses of collections from underexplored and unexplored regions and ecosystems, and the bdelloid and sessile rotifers using integrative taxonomic approaches.

Key words. Biodiverse rotifers, diverse environs, regional disparity, richness, Rotifera paradox

INTRODUCTION

Rotifera or 'wheel animalcules' colonize diverse aquatic and semi-aquatic environs with endless profusion of body forms well adapted to their living habits and habitats. These features along with the latitudinal variations vs. 'tropic' and 'temperate' centered origin of various taxa (Pejler 1977, Dumont 1983, Segers 1996, 2001, 2008) characterize these metazoans as useful models for assessing patterns in global and regional biodiversity as well as biogeography analyses. The studies on the Indian Rotifera were initiated in West Bengal (Anderson 1889) and indicated useful earlier faunal surveys of Murray (1906), Edmondson & Hutchinson (1934), Nayar (1968) and Wulfert (1966). Sharma & Michael (1980) provided an overview of taxonomic studies until 1980's, while the state-of-art reports (Sharma

1991, 1996, 1998a) and useful but unvalidated compilation by Dhanapathi (2000) traced the subsequent faunal diversity progress which lacked a definite focus on biodiversity and biogeography until the end of the 20th century. The period from beginning of the 21st century to-date indicated notable Rotifera biodiversity works from the states of Arunachal Pradesh (Sharma & Sharma 2019a), Jammu & Kashmir (Sharma & Sharma 2018a), Mizoram (Sharma & Sharma 2015a), Nagaland (Sharma *et al.* 2017), and Tamil Nadu (Sharma & Sharma 2009). Meta-diversity updates on NEI Rotifera (Sharma & Sharma 2005, 2014a, 2019b), and the reviews on the Indian species of Lecanidae (Sharma & Sharma 2014b), Brachionidae (Sharma & Sharma 2014c), Lepadellidae (Sharma & Sharma 2015b) and *Testudinella* (Sharma & Sharma 2018b) notably added to our understanding of the rotifer diversity of India. This

period also indicated certain important biodiversity studies from the floodplains of Assam (Sharma 2005, 2014; Sharma & Sharma 2008, 2014d, 2019c, 2019d, Sharma *et al.* 2017, 2018) and Manipur (Sharma 2009a) states of NEI, and the river Yamuna floodplains (Arora & Mehra 2003). Besides, our studies provided useful database for meta-analysis of Rotifera diversity of Deepor beel (Sharma & Sharma 2011, 2012, 2013, 2015c) and Loktak Lake (Sharma 2009b; Sharma & Sharma 2018c; Sharma *et al.* 2016) – the two intensively sampled Ramsar sites of India.

This study aims to present a critical appraisal of the current biodiversity status of the Indian Rotifera based on our contributions from various regions of India *vis-a-vis* intensive sampling from NEI; the semi-intensive collections from Jammu & Kashmir (western Himalayas) and West Bengal (east India) and Tamil Nadu (south India); the studies (BKS, unpublished) from central, east and south India; and evaluation of other viable reports published over the last nearly 130 years. A detailed systematic list of 434 valid Rotifera species known to-date from India is presented. Comments are made on biodiversity and biogeography of the Indian Rotifera with reference to nature and composition, species of global and regional distribution significance, spatial heterogeneity and regional disparity of the biodiversity, and species richness of the rotifer assemblages in various aquatic ecosystems. In addition, we highlight existing lacunae and suggest areas needing attention for the future biodiversity studies on the taxon.

MATERIALS AND METHODS

This biodiversity assessment is primarily based on analyses of our plankton and semi-planktonic samples collected from the diverse lentic environs of various regions of India over the last three decades. In addition, we undertook validation of the viable taxa vide the published reports. All our collections were obtained by towing nylobolt

plankton net (# 40µm) and were preserved in 5% formalin. Voucher collections are deposited in the national holdings of Zoological Survey of India, Kolkata. We examined the collections from the following regions / states of India (Fig. 1):

1. Northeast India – Arunachal Pradesh, Assam, Manipur, Mizoram, Meghalaya, Nagaland and Tripura (Fig. 2).
2. Eastern India – West Bengal, Odisha (Orissa), Bihar and Jharkhand.
3. North India – Jammu & Kashmir, Punjab, Haryana.
4. Central India – Madhya Pradesh, Maharashtra and Goa.
5. South India – Andhra Pradesh, Telangana, Tamil Nadu, Karnataka and Kerala.
6. Insular freshwaters off the south Andamans Islands.

Microphotographs were taken by a Leica (DM 1000) stereoscopic phase contrast microscope fitted with an image analyzer and the figures were drawn with a drawing tube attachment. Rotifera species were identified following Koste (1978), Koste & Shiel (1987, 1989, 1990), Shiel & Koste (1992), Segers (1995, 1996), Sharma (1983, 1987a, 1987b, 1998b), Sharma & Sharma (1987, 1999, 2000, 2008, 2013, 2014b, 2014c, 2015a, 2019b) and Jersabek and Leitner (2013). Segers (2002, 2007) and Jersabek & Leitner (2013) were followed for classification, nomenclature, and biogeography of the taxon. Unless indicated otherwise, the figures and the micro-photographs are based on our collections from different parts of India.

RESULTS

A total of 434 Rotifera species belonging to 25 families and 68 genera are considered as validly known from India based on our present biodiversity assessment. A detailed systematic list of the documented taxa is presented hereunder:

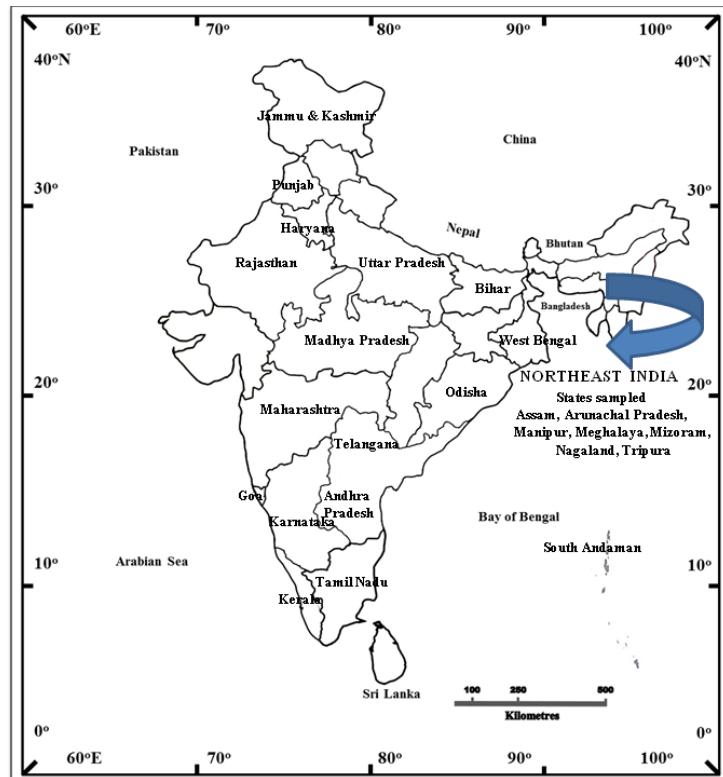


Figure 1. Map of India showing the sampled states

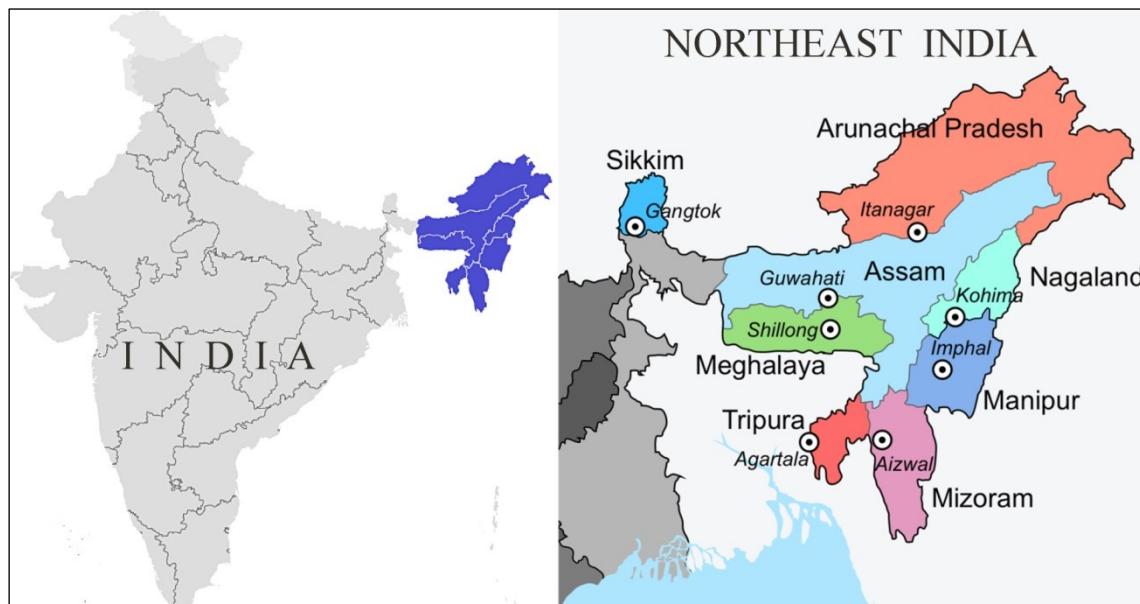


Figure 2. A = Map of India showing northeast India (blue color), B = map of NEI indicating the sampled states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura (After Sharma & Sharma 2019b)

Systematic list of Rotifera recorded from India

Phylum: Rotifera

Class: Eurotatoria

Subclass: Monogononta

Order: Ploima

Family: Brachionidae

1. *Anuraeopsis coelata* De Beauchamp, 1932 *
2. *A. fissa* (Gosse, 1851) *
3. *A. navicula* Rousselet, 1911 *
4. *Brachionus ahlstromi* Lindeman, 1939 *
5. *B. angularis* Gosse, 1851 s. *lato* *
6. *B. angularis bidens* Plate, 1886 *
7. *B. bennini* Leissling, 1924 *
8. *B. bidentatus* Anderson, 1889 s. *lato* *
9. *B. budapestinensis* Daday, 1885 *
10. *B. calyciflorus* Pallas, 1766 s. *lato* *
11. *B. caudatus* Barrois & Daday, 1894 s. *lato* *
12. *B. dichotomus reductus* Koste & Shiel, 1980 *
13. *B. dimidiatus* Bryce, 1931 *
14. *B. diversicornis* (Daday, 1883) s. *lato* *
15. *B. donneri* Brehm, 1951 *
16. *B. dorcas* Gosse, 1851 *
17. *B. durgae* Dhanapathi, 1974 *
18. *B. falcatus* Zacharias, 1898 s. *lato* *
19. *B. falcatus reductus* Koste & Shiel, 1987 *
20. *B. forficula* Wierzejski, 1891 s. *lato* *
21. *B. kostei* Shiel, 1983 *
22. *B. leydigii* Cohn, 1862 *
23. *B. lyratus* Shephard, 1911 *
24. *B. mirabilis* Daday, 1897 *
25. *B. murphyi* Sudzuki, 1989 *
26. *B. nilsoni* Ahlstrom, 1940 *
27. *B. plicatilis* O.F. Muller, 1786 s. *lato* *
28. *B. pterodinoides* Rousselet, 1913 *
29. *B. quadridentatus* Hermann, 1783 s. *lato* *
30. *B. rotundiformis* Tschugunoff, 1921 *
31. *B. rubens* Ehrenberg, 1838 *
32. *B. sessilis* Varga, 1951 *
33. *B. srisumonae* Segers, Kotetip & Sanoamuang, 2004 *
34. *B. urceolaris* O. F. Muller, 1773 *
35. *K. kellicottia longispina* (Kellicott, 1879) *
36. *K. keratella cochlearis* (Gosse, 1851) s. *lato* *
37. *K. edmondsoni* Ahlstrom, 1943 *
38. *K. javana* Hauer, 1937 *
39. *K. hiemalis* Carlin, 1943 *
40. *K. lenzi* Hauer, 1953 *
41. *K. procurva* (Thorpe, 1891) *
42. *K. quadrata* (O.F. Muller, 1786) *
43. *K. serrulata* (Ehrenberg, 1838) *
44. *K. tecta* (Gosse, 1851) *

43. *K. tictinensis* (Callerio, 1921) *
44. *K. tropica* (Apstein, 1907) s. *lato* *

45. *Notholca acuminata* (Ehrenberg, 1832) *
46. *N. labis* Gosse, 1887

47. *N. squamula* (O.F. Muller, 1786) *
48. *N. striata* (Müller, 1786) *

49. *Plationus patulus* (O.F. Muller, 1786) s. *lato* *
50. *Platyias lelooupi* (Gillard, 1967) *

51. *P. quadricornis* (Ehrenberg, 1832) *
52. *P. quadricornis andhraensis* Dhanapathi, 1974 *

Family: Epiphanidae

52. *Cyrtonia tuba* (Ehrenberg, 1834)
53. *Epiphantes brachionus* (Ehrenberg, 1837) s. *lato* *
54. *E. brachionus spinosa* (Rousselet, 1901) *
55. *E. clavatula* (Ehrenberg, 1831) *
56. *E. macroura* (Barrois & Daday, 1894) *
57. *E. senta* (O.F. Muller, 1773) *
58. *Mikrocoides chlaena* (Gosse, 1886)

Family: Euchlanidae

59. *Beauchampiella eudactylota* (Gosse, 1886) *
60. *Dipleuchlanis ornata* Segers, 1993 *
61. *D. propatula* (Gosse, 1886) *
62. *Euchlanis alata* Voronkov, 1912
63. *E. deflexa* Gosse, 1851
64. *E. dilatata* Ehrenberg, 1832 s. *lato* *
65. *E. incisa* Carlin, 1939 *
66. *E. meneta* Myers, 1930 *
67. *E. orophila* Gosse, 1887 *
68. *E. semicarinata* Segers, 1993 *
69. *E. triquetra* Ehrenberg, 1838 *
70. *Pseudoeuchlanis longipedes* Dhanapathi, 1978 *
71. *Tripleuchlanis plicata* (Levander, 1894) *

Family: Mytilinidae

72. *Lophocharis naias* Wulfert, 1942
73. *L. oxysternon* (Gosse, 1851) *
74. *L. salpina* (Ehrenberg, 1834) *
75. *Mytilina acanthophora* Hauer, 1938 *
76. *M. bisulcata* (Lucks, 1912) *
77. *M. brevispina* (Ehrenberg, 1830) *
78. *M. lobata* Pourriot, 1996 *
79. *M. michelangellii* Reid & Turner, 1988 *
80. *M. mucronata* (O.F. Muller, 1773) *
81. *M. ventralis* (Ehrenberg, 1830) s. *lato* *

Family: Trichotriidae

82. *Macrochaetus collinsi* (Gosse, 1867) *
83. *M. danneelae* Koste & Shiel, 1983 *
84. *M. longipes* Myers, 1934 *
85. *M. sericus* (Thorpe, 1893) *

86. *M. subquadratus* Perty, 1850 *

87. *Trichotria pocillum* (O.F. Muller, 1776) *

88. *T. tetractis* (Ehrenberg, 1830) *s. lato* *

89. *Wolga spinifera* (Western, 1894) *

Family: Lepadellidae

90. *Colurella adriatica* Ehrenberg, 1831 *

91. *C. colurus* (Ehrenberg, 1830) *s. lato* *

92. *C. obtusa* (Gosse, 1886) *s. lato* *

93. *C. oxycauda* Carlin, 1939

94. *C. sanoamuangae* Chittapun, Pholpunthin & Segers, 1999 *

95. *C. sulcata* (Stenroos, 1898) *

96. *C. tesselata* (Glascott, 1893) *

97. *C. uncinata* (O.F. Muller, 1773) *s. lato* *

98. *Lepadella acuminata* (Ehrenberg, 1834) *s. lato* *

99. *L. apsicora* Myers, 1934 *

100. *L. apsida* Harring, 1916 *

101. *L. benjaminae* Harring, 1916 *

102. *L. bicornis* Vasisht & Battish, 1971 *

103. *L. biloba* Hauer, 1958 *

104. *L. costatoides* Segers, 1992 *s. lato* *

105. *L. cristata* (Rousselet, 1893) *

106. *L. dactyliseta* (Stenroos, 1898) *

107. *L. desmeti* Segers & Chittapun, 2001 *

108. *L. discoidea* Segers, 1993 *

109. *L. ehrenbergi* (Perty, 1850) *

110. *L. elongata* Koste, 1992 *

111. *L. eurysterna* Myers, 1942 *

112. *L. cf. favorita* Klement, 1962 *

113. *L. heterodactyla* Fadeew, 1925 *

114. *L. heterostyla* (Murray, 1913) *

115. *L. imbricata* Harring, 1914 *

116. *L. kostei* Wulfert, 1966

117. *L. latusinus* (Hilgendorf, 1889) *

118. *L. lindaui* Koste, 1981 *

119. *L. longiseta* Myers, 1934 *

120. *L. minoroides* Koste & Robertson, 1983 *

121. *L. minuta* (Weber & Montet, 1918) *

122. *L. nartiangensis* Sharma & Sharma, 1987 *

123. *L. neglecta* Segers & Dumont, 1995 *

124. *L. ovalis* (O.F. Muller, 1786) *s. lato* *

125. *L. patella patella* (O.F. Muller, 1773) *s. lato* *

L. patella oblonga (Ehrenberg, 1834) *

L. patella persimilis De Ridder, 1961

126. *L. quadricarinata* (Stenroos, 1898) *

127. *L. quinquecostata* (Lucks, 1912) *

128. *L. rhombooides* (Gosse, 1886) *s. lato* *

129. *L. rhomboidula* (Bryce, 1890) *

130. *L. triba* Myers, 1934 *

131. *L. triptera* Ehrenberg, 1832 *s. lato* *

132. *L. vandenbrandei* Gillard, 1952 *

133. *Squatinella bifurca* (Bolton, 1884) *

134. *S. lamellaris* (O. F. Müller, 1786) *

Family: Lecanidae

135. *Lecane acanthinula* (Hauer, 1938) *

136. *L. aculeata* (Jakubski, 1912) *

137. *L. arcuata* (Bryce, 1891) *

138. *L. arcula* Harring, 1914 *

139. *L. aeganea* Harring, 1914 *

140. *L. aspasia* Myers, 1917 *

141. *L. batillifer* (Murray, 1913) *

142. *L. bifastigata* Hauer, 1938 *

143. *L. bifurca* (Bryce, 1892) *

144. *L. blachei* Berzins, 1973 *

145. *L. braumi* Koste, 1988 *

146. *L. bulla bulla* (Gosse, 1851) *s. lato* *

L. bulla diabolica (Hauer, 1936) *

147. *L. calcaria* Harring & Myers, 1926 *

148. *L. clara* (Bryce, 1892) *

149. *L. closterocerca* (Schmarda, 1859) *s. lato* *

150. *L. cornuta* (Müller, 1786) *s. lato* *

151. *L. crenata* (Harring, 1913) *

152. *L. crepida* Harring, 1914 *

153. *L. curvicornis* (Murray, 1913) *s. lato* *

154. *L. decipiens* (Murray, 1913) *

155. *L. depressa* (Bryce, 1891)

156. *L. dorysimilis* Trinh Dang, Segers & Sanoamuang, 2015 *

157. *L. doryssa* Harring, 1914 *

158. *L. elasma* Harring & Myers, 1926

159. *L. elegans* Harring, 1914 *

160. *L. elongata* Harring & Myers, 1926 *

161. *L. eswari* Dhanapathi, 1976 *

162. *L. flexilis* (Gosse, 1886) *s. lato* *

163. *L. furcata* (Murray, 1913) *s. lato* *

164. *L. galeata* (Bryce, 1892)

165. *L. glypta* Harring & Myers, 1926 *

166. *L. haliclysta* Harring & Myers, 1926 *

167. *L. hamata* (Stokes, 1896) *s. lato* *

168. *L. hastata* (Murray, 1913) *

169. *L. hornemannii* (Ehrenberg, 1834) *

170. *L. inermis* (Bryce, 1892) *

171. *L. inopinata* Harring & Myers, 1926 *

172. *L. isanensis* Sanoamuang & Savatenalinton, 2001 *

173. *L. jaintiaensis* Sharma, 1987 *

174. *L. lateralis* Sharma, 1978 *

175. *L. latissima* Yamamoto, 1951 *

176. *L. leontina* (Turner, 1892) *s. lato* *

177. *L. levistyla* (Olofsson, 1917) *

178. *L. ligona* (Dunlop, 1901) *

179. *L. ludwigii* (Eckstein, 1883) *s. lato* *

180. *L. luna* (Müller, 1776) *s. lato* *

181. *L. lunaris* (Ehrenberg, 1832) *s. lato* *

182. *L. marchantaria* Koste & Robertson, 1983 *

183. *L. monostyla* (Daday, 1897) *s. lato* *

184. *L. nana* (Murray, 1913) *

185. *L. nitida* (Murray, 1913) *

186. *L. niwati* Segers, Kothetip & Sanoamuang, 2004 *

187. *L. obtusa* (Murray, 1913) *s. lato* *

188. *L. ohioensis* (Herrick, 1885) *

189. *L. papuana* (Murray, 1913) *s. lato* *

190. *L. pawlowskii* Wulfert, 1966 *

191. *L. paxiana* Hauer, 1940 *

192. *L. perplexa* (Ahlstrom, 1938)

193. *L. pertica* Harring & Myers, 1926 *

194. *L. ploenensis* (Voigt, 1902) *

195. *L. punctata* (Murray, 1913)

196. *L. pusilla* Harring, 1914 *

197. *L. pyriformis* (Daday, 1905) *

198. *L. quadridentata* (Ehrenberg, 1830) *s. lato* *

199. *L. rhenana* Hauer, 1929 *

200. *L. rhytida* Harring & Myers, 1926 *

201. *L. rugosa* (Harring, 1914) *

202. *L. ruttneri* Hauer, 1938 *

203. *L. schraederi* Wulfert, 1966 *

204. *L. scutata* (Harring & Myers, 1926) *

205. *L. shieli* Segers & Sanoamuang, 1994 *

206. *L. signifera* (Jennings, 1896) *s. lato* *

207. *L. simonneae* Segers, 1993 *

208. *L. sinuata* (Hauer, 1938) *

209. *L. sola* Hauer, 1936 *

210. *L. solfatara* (Hauer, 1938) *

211. *L. stichaea* Harring, 1913 *

212. *L. stichoclysta* Segers, 1993 *

213. *L. stenroosi* (Meissner, 1908) *

214. *L. stokesii* (Pell, 1890) *

215. *L. styrax* (Harring & Myers, 1926) *

216. *L. superaculeata* Sanoamuang & Segers, 1997 *

217. *L. sympoda* Hauer, 1929 *

218. *L. syngenes* (Hauer, 1938) *

219. *L. tenuiseta* Harring, 1914 *

220. *L. thalera* (Harring & Myers, 1926)

221. *L. thienemanni* (Hauer, 1938) *

222. *L. tryphema* Harring & Myers, 1926

223. *L. undulata* Hauer, 1938 *

224. *L. unguitata* (Fadeev, 1925) *s. lato* *

225. *L. ungulata* (Gosse, 1887) *s. lato* *

226. *L. vasishti* Sharma, 1980 *

227. *L. verecunda* Harring & Myers, 1926 *

Family: Proalidae

228. *Proales decipiens* (Ehrenberg, 1832)

229. *P. fallaciosa* Wulfert, 1937

230. *P. indirae* Wulfert, 1966

Family: Notommatidae

231. *Cephalodella auriculata* (O.F. Müller, 1773) *

232. *C. catellina* (O.F. Müller, 1786) *

233. *C. exigua* (Gosse, 1886) *

234. *C. forficata* (Ehrenberg, 1832) *

235. *C. forficula* (Ehrenberg, 1838) *

236. *C. gibba* (Ehrenberg, 1830) *

237. *C. gigantea* Remane, 1933

238. *C. hiulca* Myers, 1924

239. *C. intuta* Myers, 1924 *

240. *C. megalcephala* (Glascott, 1893)

241. *C. misgurnus* Wulfert, 1937

242. *C. mucronata* Myers, 1924 *

243. *C. panarista* Myers, 1924 *

244. *C. trigona* (Rousselet, 1895) *

245. *C. ventripes* (Dixon-Nuttall, 1901) *

246. *Eosphora anthadis* Harring & Myers, 1922

247. *E. najas* Ehrenberg, 1830

248. *Itura aurita* (Ehrenberg, 1830)

249. *Monommata actices* Myers, 1930

250. *M. grandis* Tessin, 1890 *

251. *M. longiseta* (O.F. Müller, 1786) *

252. *M. maculata* Harring & Myers, 1930 *

253. *Notommata aurita* (Müller, 1786)

254. *N. copeus* Ehrenberg, 1834 *

255. *N. glyphura* Wulfert, 1935 *

256. *N. pachyura* (Gosse, 1886) *

257. *N. pseudocerberus* De Beauchamp, 1908

258. *N. saccigera* Ehrenberg, 1830 *

259. *N. spinata* Koste & Shiel, 1991 *

260. *N. tripus* Ehrenberg, 1838 *

261. *Taphrocampa annulosa* Gosse, 1851 *

262. *T. selenura* Gosse, 1887 *

Family: Scaridiidae

263. *Scaridium longicaudum* (O.F. Müller, 1786) *

Family: Gastropodidae

264. *Ascomorpha. ecaudis* Perty, 1850 *

265. *A. saltans* Bartsch, 1870 *

A. saltans indica Wulfert, 1966

266. *A. ovalis* (Bergendal, 1892) *

267. *Gastropus hytopus* (Ehrenberg, 1838) *

268. *G. minor* (Rousselet, 1892) *

269. *G. stylifer* Imhof, 1891 *

Family: Trichocercidae

270. *Ascomorphella volvocicola* (Plate, 1886)

271. *Trichocerca abilioi* Segers & Sarma, 1993 *

272. *T. bicristata* (Gosse, 1887) *

273. *T. bidens* (Lucks, 1912) *

274. *T. brachyura* (Gosse, 1851)

275. *T. brasiliensis* (Murray, 1913) *

276. *T. capucina* (Wierzejski & Zacharias, 1893) *

277. *T. cavia* (Gosse, 1886)

278. *T. chattoni* (De Beauchamp, 1907)

279. *T. cylindrica* (Imhof, 1891) *

280. *T. edmondsoni* (Myers, 1936) *

281. *T. elongata* (Gosse, 1886) *

282. *T. flagellata* Hauer, 1937 *

283. *T. hollaerti* De Smet, 1990 *

- 284. *T. iernis* (Gosse, 1887) *
- 285. *T. insignis* (Herrick, 1885) *
- 286. *T. insulana* (Hauer, 1937) *
- 287. *T. kostei* Segers, 1993 *
- 288. *T. longiseta* (Schrank, 1802) *
- 289. *T. maior* (Hauer, 1935)*
- 290. *T. mus* Hauer, 1938 *
- 291. *T. myersi* (Hauer, 1931)
- 292. *T. porcellus* (Gosse, 1881) *
- 293. *T. pusilla* (Jennings, 1903) *
- 294. *T. rattus* (O.F. Müller, 1776) *s. lato* *
- 295. *T. ruttneri* Donner, 1953 *
- 296. *T. scipio* (Gosse, 1886) *
- 297. *T. siamensis* Segers & Pholpunthin, 1997 *
- 298. *T. similis* (Wierzejski, 1893) *s. lato* *
- 299. *T. stylata* (Gosse, 1851) *
- 300. *T. sulcata* (Jennings, 1894) *
- 301. *T. taurocephala* (Hauer, 1931) *
- 302. *T. tenuior* (Gosse, 1886) *
- 303. *T. tigris* (O.F. Müller, 1786)
- 304. *T. uncinata* (Voigt, 1902) *
- 305. *T. voluta* (Murray, 1913) *
- 306. *T. weberi* (Jennings, 1903) *

Family: Asplanchnidae

- 307. *Asplanchna brightwelli* Gosse, 1850 *
- 308. *A. herricki* de Guerne, 1888
- 309. *A. intermedia* Hudson, 1886 *
- 310. *A. priodonta* Gosse, 1850 *
- 311. *A. sieboldii* (Leydig, 1854) *
- 312. *Asplanchnopus bhimavaramensis* Dhanapathi, 1975 *
- 313. *A. hyalinus* Harring, 1913 *
- 314. *A. multiceps* (Schrank, 1793)

Family: Synchaetidae

- 315. *Ploesoma hudsoni* (Imhof, 1891) *
- 316. *P. lenticulare* Herrick, 1885 *
- 317. *Polyarthra euryptera* Wierzejski, 1891*
- 318. *P. cf. dolichoptera* Idelson, 1925 *
- 319. *P. indica* Segers & Babu, 1999
- 320. *P. vulgaris* Carlin, 1943 *s. lato* *
- 321. *Synchaeta oblonga* Ehrenberg, 1832 *
- 322. *S. longipes* Gosse, 1887 *
- 323. *S. pectinata* Ehrenberg, 1832 *
- 324. *S. stylata* Wierzejski, 1893 *
- 325. *S. tremula* (O.F. Müller, 1786) *

Family: Dicranophoridae

- 326. *Dicranophoroides caudatus* (Ehrenberg, 1834) *
- 327. *Dicranophorus dolerus* Harring & Myers, 1928 *
- 328. *D. epicharis* Harring & Myers, 1928 *
- 329. *D. forcipatus* (O.F. Müller, 1786) *
- 330. *D. luetkeni* (Bergendal, 1892) *
- 331. *D. myriophylli* (Harring, 1913)

- 332. *D. tegillus* Harring & Myers, 1928
- 333. *Encentrum longipes* Wulfert, 1936

Order: Flosculariaceae

Family: Flosculariidae

- 334. *Beauchampia crucigera* (Dutrochet, 1812)
- 335. *Floscularia conifera* (Hudson, 1886) *
- 336. *F. ringens* (Linnaeus, 1758) *s. lato* *
- 337. *Lacinularia flosculosa* (O.F. Müller, 1773) *
- 338. *L. racemovata* Thorpe, 1893 *
- 339. *Limnias ceratophylli* Schrank, 1803 *s. lato* *
- 340. *L. melicerta* Weisse, 1848
- 341. *Ptygura barbata* (Edmondson, 1939)
- 342. *P. furcillata* (Kellicott, 1889)
- 343. *P. kostei* José De Paggi, 1996
- 344. *P. melicerta* Ehrenberg, 1832 *
- 345. *P. pedunculata* Edmondson, 1939
- 346. *P. stephanion* (Anderson, 1889)
- 347. *P. tacita* Edmondson, 1940 *
- 348. *Sinantherina procera* (Thorpe, 1893)
- 349. *S. semibullata* (Thorpe, 1893) *
- 350. *S. socialis* (Linne, 1758) *
- 351. *S. spinosa* (Thorpe, 1893) *
- 352. *Stephanoceros fimbriatus* (Goldfusz, 1820) *

Family: Conochilidae

- 353. *Conochilus dossuarius* Hudson, 1885 *
- 354. *C. natans* Seligo 1901*
- 355. *C. hippocrepis* (Schrank, 1803)
- 356. *C. unicornis* Rousselet, 1892*

Family: Hexarthridae

- 357. *Hexarthra bulgarica* (Wiszniewski, 1933)
- 358. *H. intermedia* (Wiszniewski, 1929) *
- 359. *H. mira* (Hudson, 1871) *
- 360. *H. oxyuris* (Zernov, 1903)

Family: Testudinellidae

- 361. *Pompholyx complanata* Gosse, 1851*
- 362. *P. sulcata* Hudson,1885 *
- 363. *Testudinella amphora* Hauer, 1938 *s. lato* *
- 364. *T. brevicaudata* Yamamoto, 1951 *
- 365. *T. dendradena* de Beauchamp, 1955 *
- 366. *T. emarginula* (Stenoos, 1898) *s. lato* *
- 367. *T. greeni* Koste, 1981 *
- 368. *T. incisa* (Ternetz, 1892)
- 369. *T. insinuata* Hauer, 1938 *
- 370. *T. mucronata* (Gosse, 1886) *
- 371. *T. parva parva* (Ternetz, 1892) *
- T. parva bidentata* (Ternetz, 1892) *
- T. parva semiparva* Hauer, 1938 *
- 372. *T. patina* (Hermann, 1783) *s. lato* *
- 373. *T. tridentata* Smirnov, 1931 *s. lato* *
- 374. *T. walkeri* Koste & Shiel, 1980 *

375. *T. sp.* Sharma & Sharma 2018b *

376. *T. sp.1* Sharma & Sharma 2018b *

Family: Trochospaeridae

377. *Filinia brachiata* (Rousselet, 1901) *

378. *F. camasecla* Myers, 1938 *

379. *F. cornuta* (Weisse, 1848) *

380. *F. longiseta* (Ehrenberg, 1834) *s. lato* *

381. *F. opoliensis* (Zacharias, 1898) *

382. *F. pejleri* Hutchinson, 1964 *

383. *F. saltator* (Gosse, 1886) *

384. *F. terminalis* (Plate, 1886) *s. lato* *

385. *Horaella brehmi* Donner, 1949 *

386. *Trochospaera aequatorialis* Semper, 1872 *

387. *T. solstitialis* Thorpe, 1893 *

Order: Collothecaceae

Family: Atrochidae

388. *Cupelopagis vorax* (Leidy, 1857) *

Family: Collothecidae

389. *Collotheca ambigua* (Hudson, 1883)

390. *C. campanulata* (Dobie, 1849) *

391. *C. hexalobata* Banik, 2000

392. *C. mutabilis* (Hudson, 1885)

393. *C. ornata* (Ehrenberg, 1832) *

394. *C. tetralobata* Banik, 2000

395. *C. tenuilobata* (Anderson, 1889)

396. *C. trilobata* (Collins, 1872)

Subclass: Bdelloidea

Family: Adinetidae

397. *Adineta vaga major* Bryce, 1893 *

A. vaga minor Bryce, 1893

398. *A. longicornis* Murray, 1906

Family: Habrotrochidae

399. *Habrotrocha angusticollis* (Murray, 1905) *

H. angusticollis attenuata (Murray, 1906) *

Of the listed Indian Rotifera, 359 species belonging to 25 families and 67 genera (Table 1) are observed in our plankton and semi-plankton collections from the different regions / states of India (Fig. 3), while 303 species (Fig. 4) belonging to 53 genera and 24 families are observed from seven states of NEI. The monogonont rotifers include 396 belonging to 22 families and 61 genera, and 339 belonging to 21 families and 53 genera from India and in our collections, respectively (Table 1). The bdelloid rotifers

400. *H. aspera* (Bryce, 1892)

401. *H. bidens* (Gosse, 1851)

402. *H. lata* (Bryce, 1892)

403. *H. leitgebii* (Zelinka, 1886)

404. *H. microcephala* (Murray, 1906)

405. *H. nodosa* (Murray, 1906)

406. *H. perforata* (Murray, 1906)

Family: Philodinidae

407. *Dissotrocha aculeata* (Ehrenberg, 1832) *

408. *Embata laticeps* (Murray, 1905)

409. *Macrotrachela bullata* (Murray, 1906)

410. *M. formosa* (Murray, 1906)

411. *M. habita* (Bryce, 1894)

412. *M. multispinosa* Thompson, 1892 *

413. *M. musculosa* (Milne, 1886)

414. *M. papillosa* Thompson, 1892

415. *M. plicata* (Bryce, 1892)

416. *M. quadricornifera rigida* Milne, 1916

417. *Philodina brevipes* Murray, 1902

418. *P. citrina* Ehrenberg, 1832*

419. *P. flaviceps* Bryce, 1906

420. *P. indica* Murray, 1906

421. *P. megalotrocha* Ehrenberg, 1832

422. *P. roseola* Ehrenberg, 1832

423. *P. squamosa* Murray, 1906

424. *P. vorax* (Janson, 1893)

425. *Rotaria citrina* (Ehrenberg, 1838) *

426. *R. macroceros* (Gosse, 1851) *

427. *R. mento* (Anderson, 1889) *

428. *R. neptunia* (Ehrenberg, 1830) *

429. *R. neptunoida* Harring, 1913*

430. *R. ovata* (Anderson, 1889)

431. *R. rotatoria* (Pallas, 1766) *

432. *R. sordida sordida* (Western, 1893)
 R. sordida fimbriata (Murray, 1906)

433. *R. tardigrada* (Ehrenberg, 1830)

434. *R. tridens* (Montet, 1915)

*Recorded in our collections from different regions of India

(Table 1) are represented by 38 species belonging to 3 families and 7 genera, while our samples reveal 11 species and four genera of bdellooids. Rotifera of NEI reveals 287 species of Monogononta and 16 species of Bdelloidea.

Lecanidae (93 species) > Brachionidae (51 species) > Lepadellidae (45 species) > Trichocercidae (37 species) > Notommatidae (32 species) and Philodinidae (27) are notable, families, while Floscularidae (19 species), Testudinellidae

(16 species), Euchlanidae (13 species), Synchaetidae (11 species), Trochosphaeridae (11 species) and Mytilinidae (10 species) are noteworthy. *Lecane* (93 species) is most speciose genus; *Trichocerca* (36 species) \geq *Lepadella* (35 species) $>$ *Brachionus* (30 species) are notable, while *Cephalodella* (15 species) \geq *Testudinella* (14 species) $>$ *Keratella* (11 species) \geq *Rotaria* (10 species) are other important genera; *Euchlanis*, *Colurella*, *Notommata*, *Filinia*, *Collotheca*, *Habrotrocha*, *Macrotrachela* and *Philodina* include eight species each and *Mytilina* includes seven species.

The family-wise breakup of the rotifer taxa known from India and in our collections are indicated in Table 1. The species observed in our collections from the different states of India are indicated in Fig. 3. Our intensive samples from seven states of NEI (Fig. 4) indicate the rotifer richness ranging between 181 ± 39 species with 244, 200, 176, 172, 162, 161 and 150 species observed from Assam, Manipur, Tripura, Arunachal Pradesh, Mizoram, Meghalaya and Nagaland, respectively.

Table 1: Family-wise composition of Rotifera

Families↓	Taxa→	Species		Genera		
		India	Our collections	India	Our collections	
Subclass : Monogononta						
Order : Ploima						
Family: Brachionidae	51	50	7	7		
Family: Epiphanidae	07	04	4	1		
Family: Euchlanidae	13	11	5	5		
Family: Mytilinidae	10	09	2	2		
Family: Trichotriidae	08	08	3	3		
Family: Lepadellidae	45	43	3	3		
Family: Lecanidae	93	88	1	1		
Family: Proalidae	03	0	1	0		
Family: Notommatidae	32	22	6	4		
Family: Scaridiidae	01	01	1	1		
Family: Gastropodidae	06	06	2	2		
Family: Trichocercidae	37	32	2	2		
Family: Asplanchnidiae	08	06	2	2		
Family: Synchaetidae	11	09	3	3		
Family: Dicranophoridae	08	05	3	2		
Order: Flosculariaceae						
Family: Flosculariidae	19	11	7	6		
Family: Conochilidae	04	03	1	1		
Family: Hexarthridiae	04	02	1	1		
Family: Testudinellidae	16	15	2	2		
Family: Trochosphaeridae	11	11	3	3		
Order: Collothecaceae						
Family: Atrochidae	01	01	1	1		
Family: Collothecidae	08	02	1	1		
Sub-class: Bdelloidea						
Family: Adinetidae	02	01	1	1		
Family: Habrotrochidae	08	01	1	1		
Family: Philodinidae	28	09	5	4		
Total Rotifer taxa	434	350	68	59		

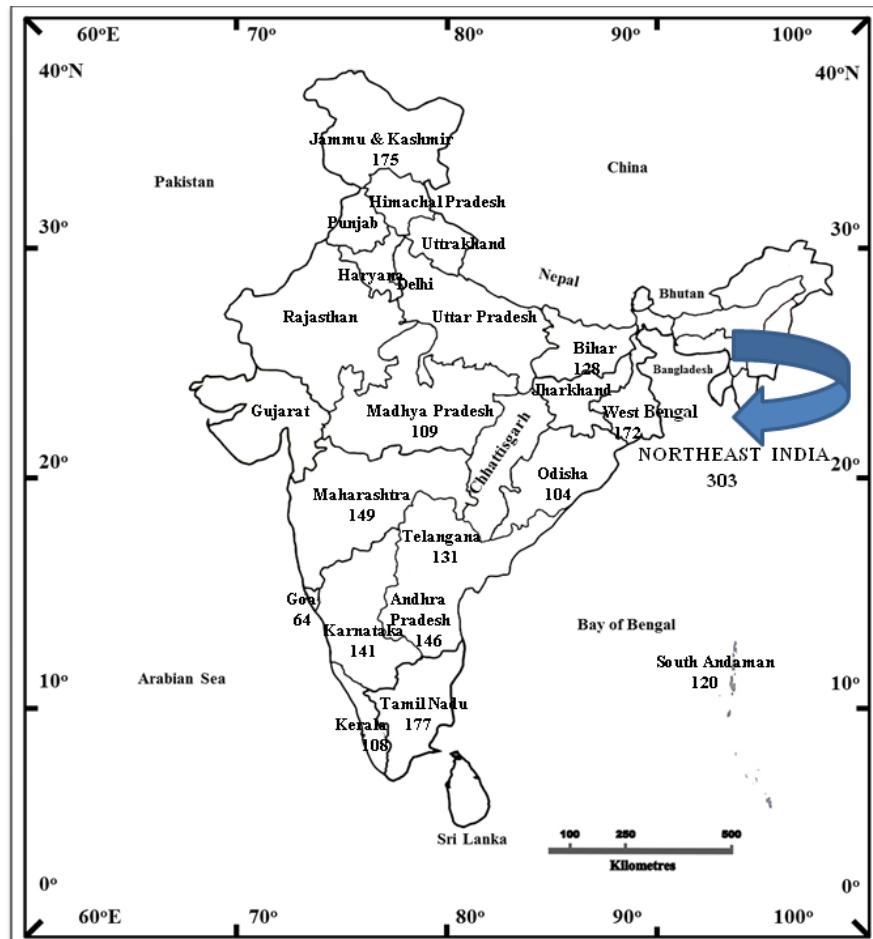


Figure 3. Species richness of Rotifera in various states of India

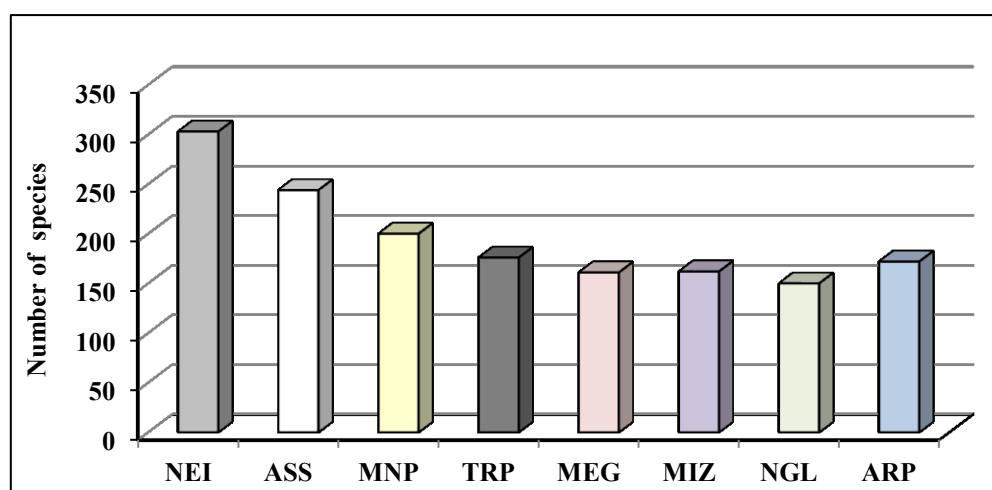


Figure 4. Rotifera species known from Northeast India
(NEI- northeast India; ASS-Assam; MNP-Manipur; TRP- Tripura; MEG-Meghalaya; MIZ-Mizoram, NGL-Nagaland; ARP-Arunachal Pradesh)

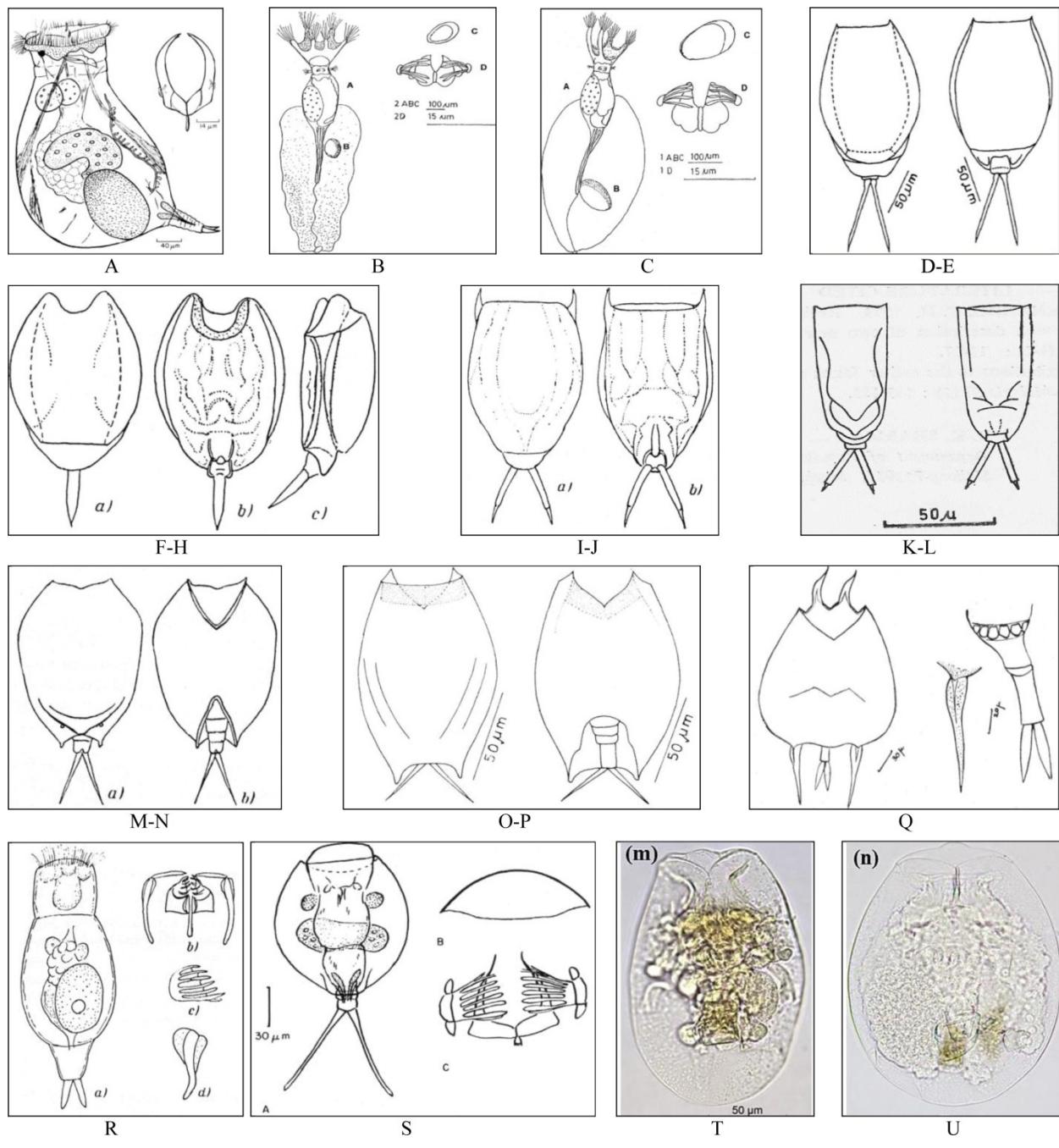


Figure 5. Indian endemics. **A** = *Asplanchnopus bhimavaramensis* Dhanapathi (lateral view and trophi, after Dhanapathi, 1975); **B** = *Collotheca hexalobata* Banik (lateral view, trophi and amictic egg, after Banik 2000); **C** = *Collotheca tetralobata* Banik (lateral view, trophi and amictic egg, after Banik 2000); **D-E** = *Lecane jaintiaensis* Sharma (dorsal and ventral view views, after Sharma 1987b); **F-H** = *Lecane schraederi* Wulfert (dorsal, ventral and lateral views); **I-J** = *Lecane pawlowski* Wulfert (dorsal and ventral views, after Wulfert, 1966); **K-L** = *Lecane vasishti* Sharma (dorsal and ventral view); **M-N** = *Lepadella kostei* Wulfert (dorsal and ventral views, after Wulfert 1966); **O-P** = *Lecane nartiangensis* Sharma & Sharma (dorsal and ventral views, after Sharma & Sharma 1987); **Q** = *Platyias quadricornis andhraensis* Dhanapathi (ventral view, after Dhanapathi, 1974); **R** = *Proales indirae* Wulfert (dorsal view, trophi, unci and ramu, after Wulfert 1966); **S** = *Pseudoeuchlanis longipedes* Dhanapathi (dorsal view, cross-section and trophi, after Dhanapathi 1978); **T** = *Testudinella* sp. (ventral view, after Sharma and Sharma 2018b); **U** = *Testudinella* sp.1 (ventral view, after Sharma & Sharma 2018b).

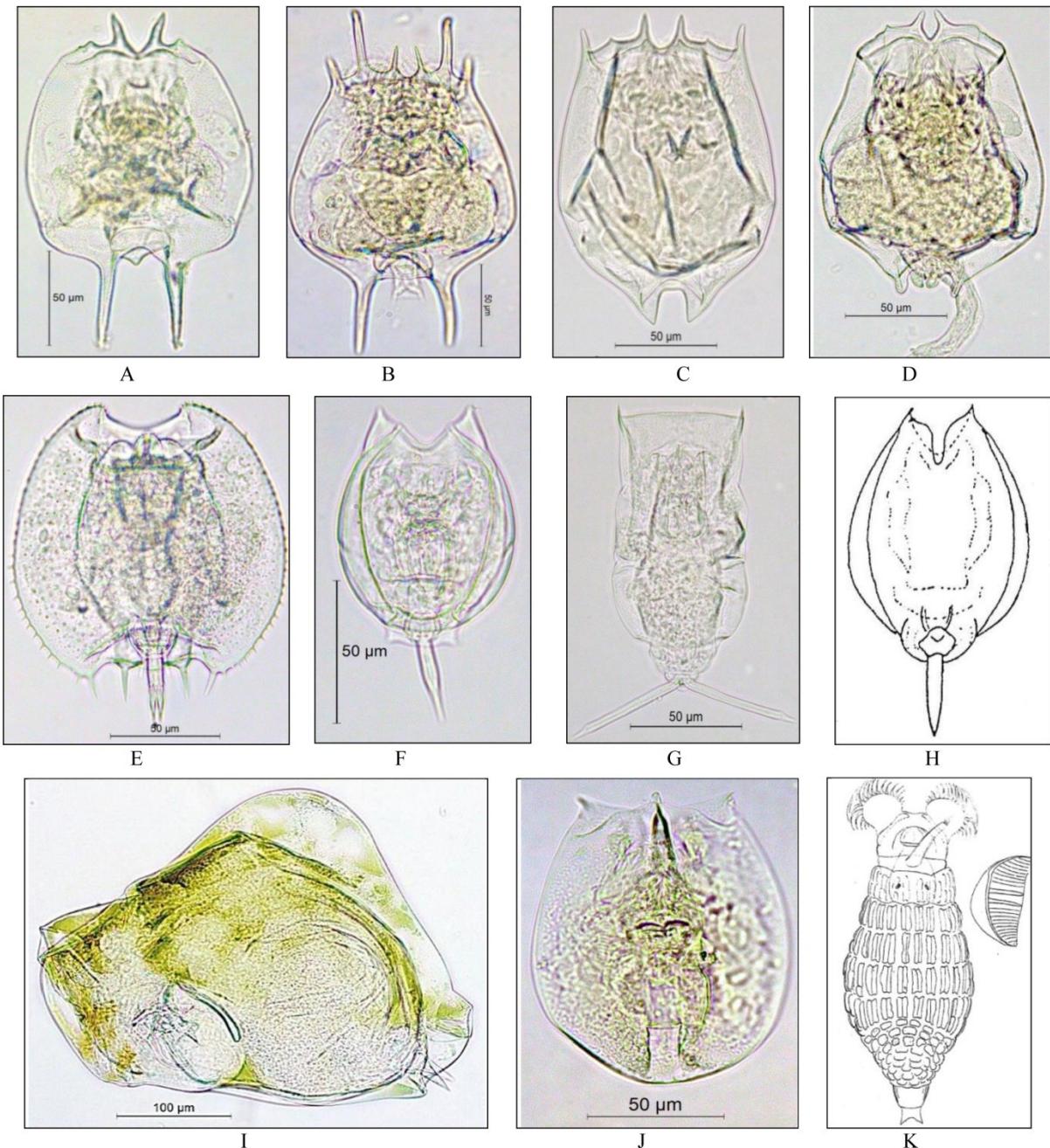


Figure 6. Australasian Rotifera. **A** = *Brachionus dichotomus reductus* Koste & Shiel (ventral view); **B** = *Brachionus falcatus reductus* Koste & Shiel (dorsal view, after Sharma & Sharma 2019b); **C** = *Brachionus kostei* Shiel (dorsal view); **D** = *Brachionus lyratus* Shephard (ventral view, after Sharma & Sharma 2019b); **E** = *Macrochaetus danneelae* Koste & Shiel (dorsal view, after Sharma & Sharma, 2019b); **F** = *Lecane batillifer* (Murray) (dorsal view); **G** = *Lecane shieli* Segers & Sanoamuang (dorsal view, after Sharma & Sharma 2019b); **H** = *Lecane sinuata* (Hauer) (ventral view, after Sharma & Sharma 2014b); **I** = *Notommata spinata* Koste & Shiel (parially compressed, lateral view); **J** = *Testudinella walkeri* Koste & Shiel (ventral view, after Sharma & Sharma 2015b); **K** = *Philodina squamosa* Murray (dorsal view and trophi, after Murray 1906).

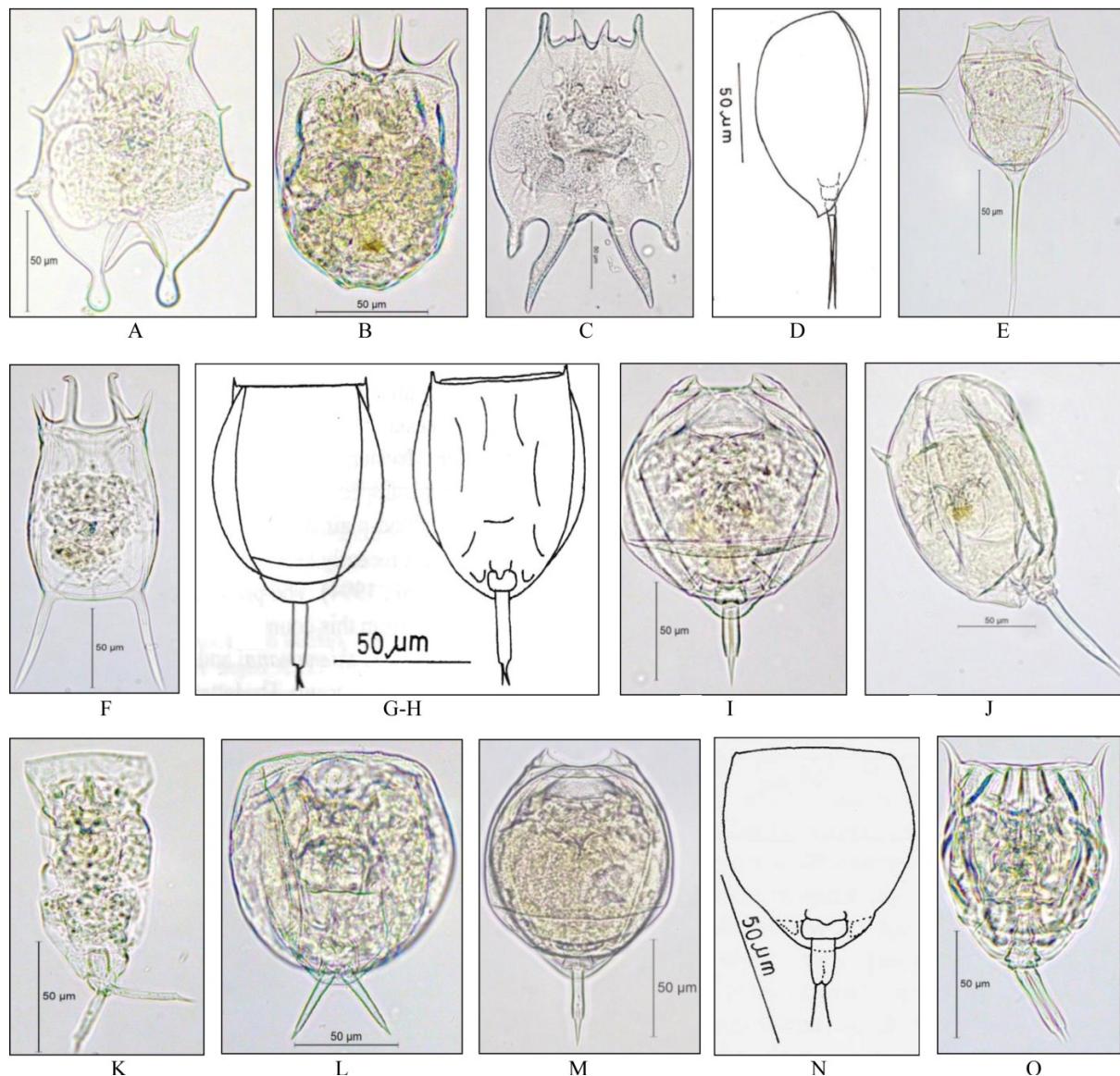


Figure 7. Oriental Rotifera. **A** = *Brachionus donneri* Brehm (ventral view); **B** = *Brachionus murphyi* Sudzuki (ventral view, after Sharma & Sharma 2019b); **C** = *Brachionus srisumonae* Segers, Kothetip & Sanoamuang (ventral view, after Sharma & Sharma 2019b); **D** = *Colurella sanoamuangae* Chittapun, Pholpunthin & Segers (lateral view, after Sharma & Sharma 2015a); **E** = *Filinia camasecla* Myers (ventral view); **F** = *Keratella edmondsoni* Ahlstrom (dorsal view); **G-H** = *Lecane acanthinula* (Hauer) (dorsal and ventral views, after Sharma & Sharma 2014b); **I** = *Lecane blachei* Berzins (ventral view); **J** = *Lecane bulla diabolica* (Hauer), lateral view; **K** = *Lecane isanensis* Sanoamuang & Savatenalinton (ventral view, after Sharma & Sharma 2019b); **L** = *Lecane latissima* Yamamoto (dorsal view); **M** = *Lecane niwati* Segers, Kothetip & Sanoamuang (ventral view); **N** = *Lecane solfatara* (Hauer) (ventral view, after Sharma 2005); **O** = *Lecane superaculeata* Sanoamuang & Segers (ventral view).

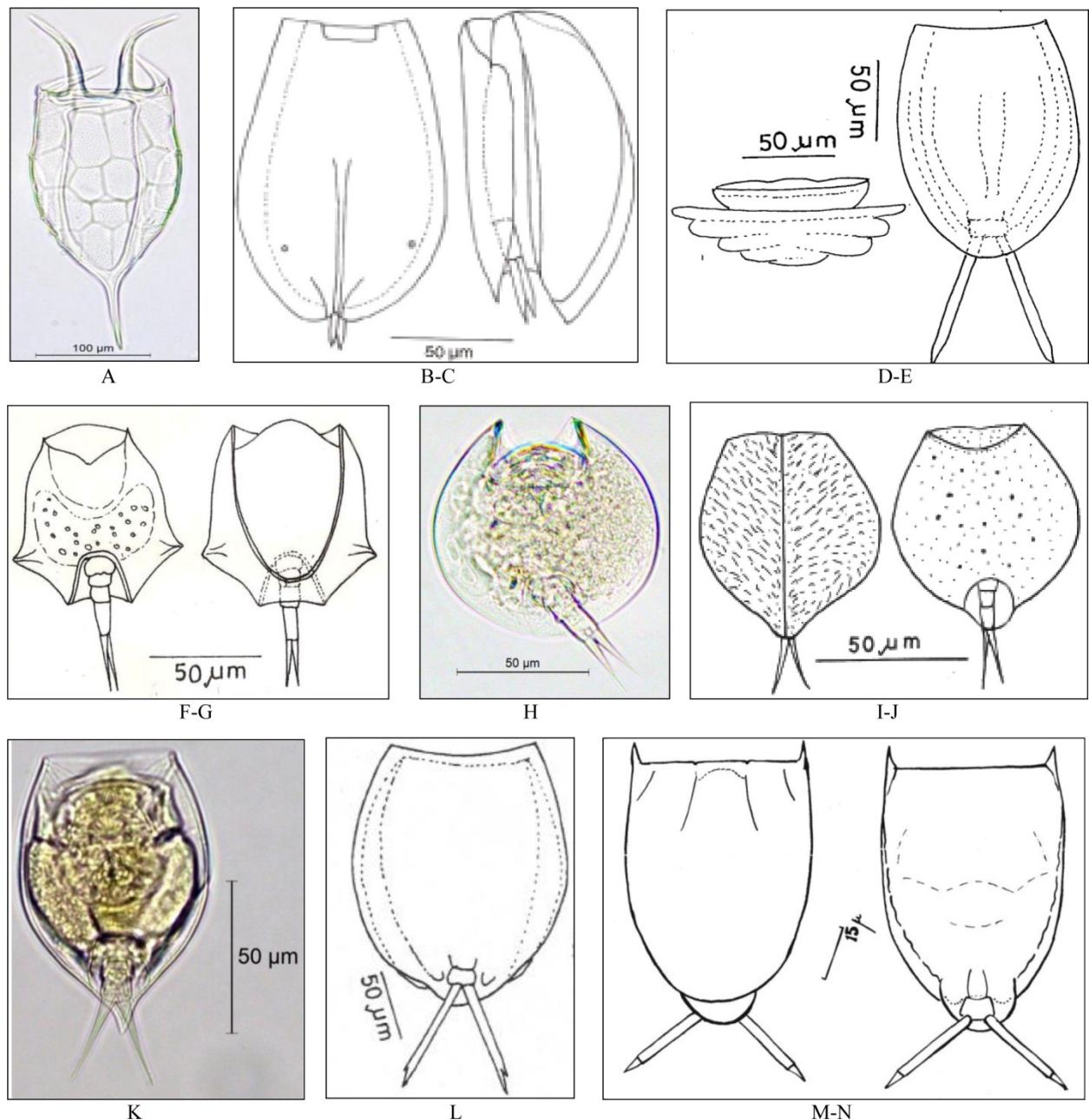


Figure 8. Paleotropical Rotifera. **A** = *Keratella javana* Hauer (ventral view); **B-C** = *Euchlanis semicarinata* Segers (dorsal and lateral views, after Sharma 2005); **D-E** = *Dipleuchlanis ornata* Segers (ventral view and cross-section, after Sharma 2005); **F-G** = *Lecane bicornis* Vasisht & Battish (ventral and dorsal views); **H** = *Lepadella discoidea* Segers (ventral view); **I-J** = *Lepadella minoruoides* Koste & Robertson (dorsal and ventral view, after Sharma 2004); **K** = *Lepadella vandenbrandei* Gillard (ventral view); **L** = *Lecane braumi*, Koste (ventral view, after Sharma & Sharma 1987); **M-N** = *Lecane eswari* Dhanapathi (dorsal and ventral views, after Dhanapathi 1976)

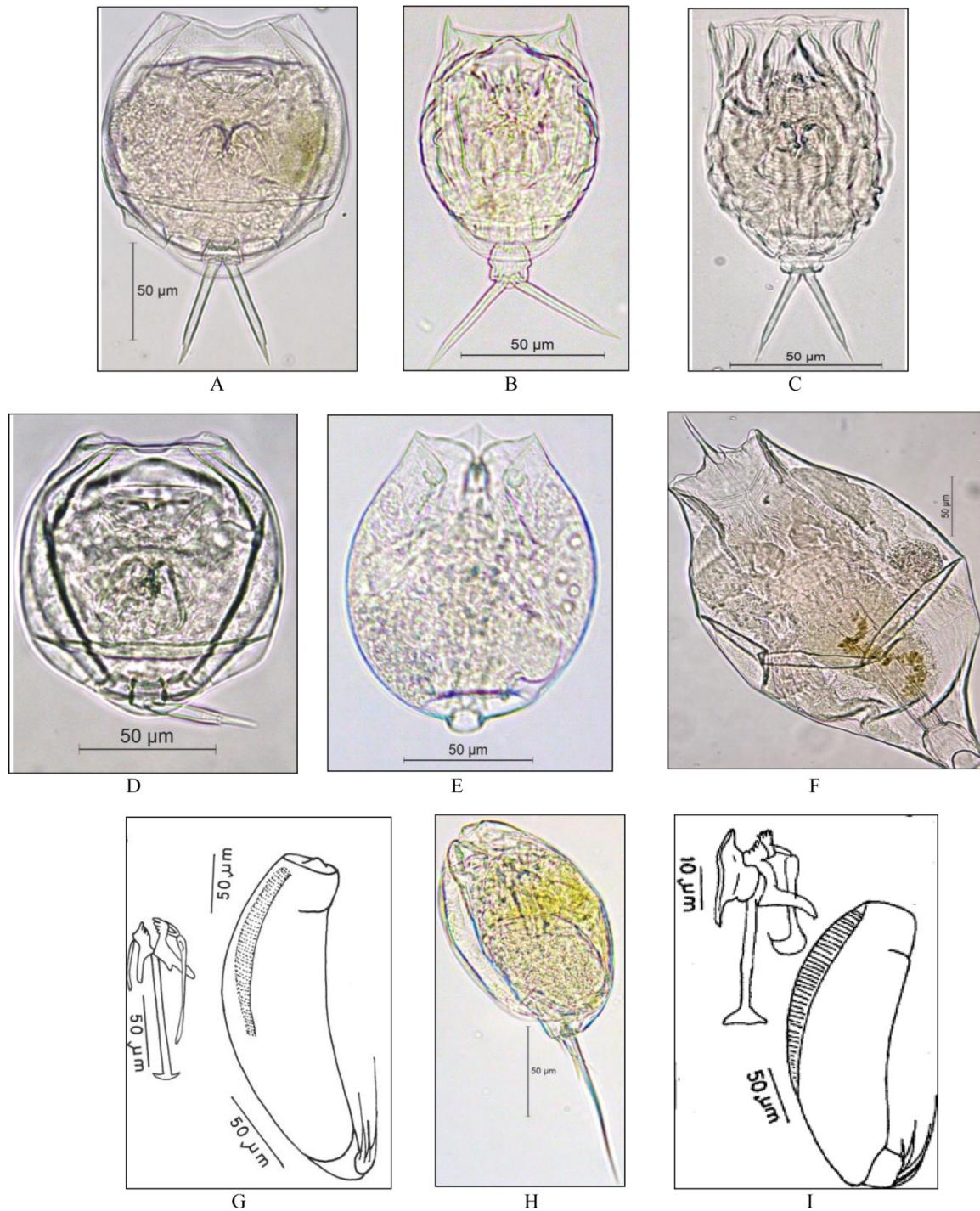


Figure 9. Paleotropical Rotifera. **A** = *Lecane lateralis* Sharma, (ventral view); **B** = *Lecane simonneae* Segers (dorsal view); **C** = *Lecane stichocysta* Segers (dorsal view, Sharma & Sharma 2019c); **D** = *Lecane unguitata* (Fadeev) (ventral view); **E** = *Testudinella brevicaudata* Yamamoto, ventral view; **F** = *Testudinella greeni* Koste (dorsal view); **G** = *Trichocerca abilioi* Segers & Sarma (lateral view and trophi, Sharma & Sharma 2008); **H** = *Trichocerca hollaerti* De Smet (lateral view); **I** = *Trichocerca kostei* Segers (lateral view and trophi, Sharma & Sharma, 2008).

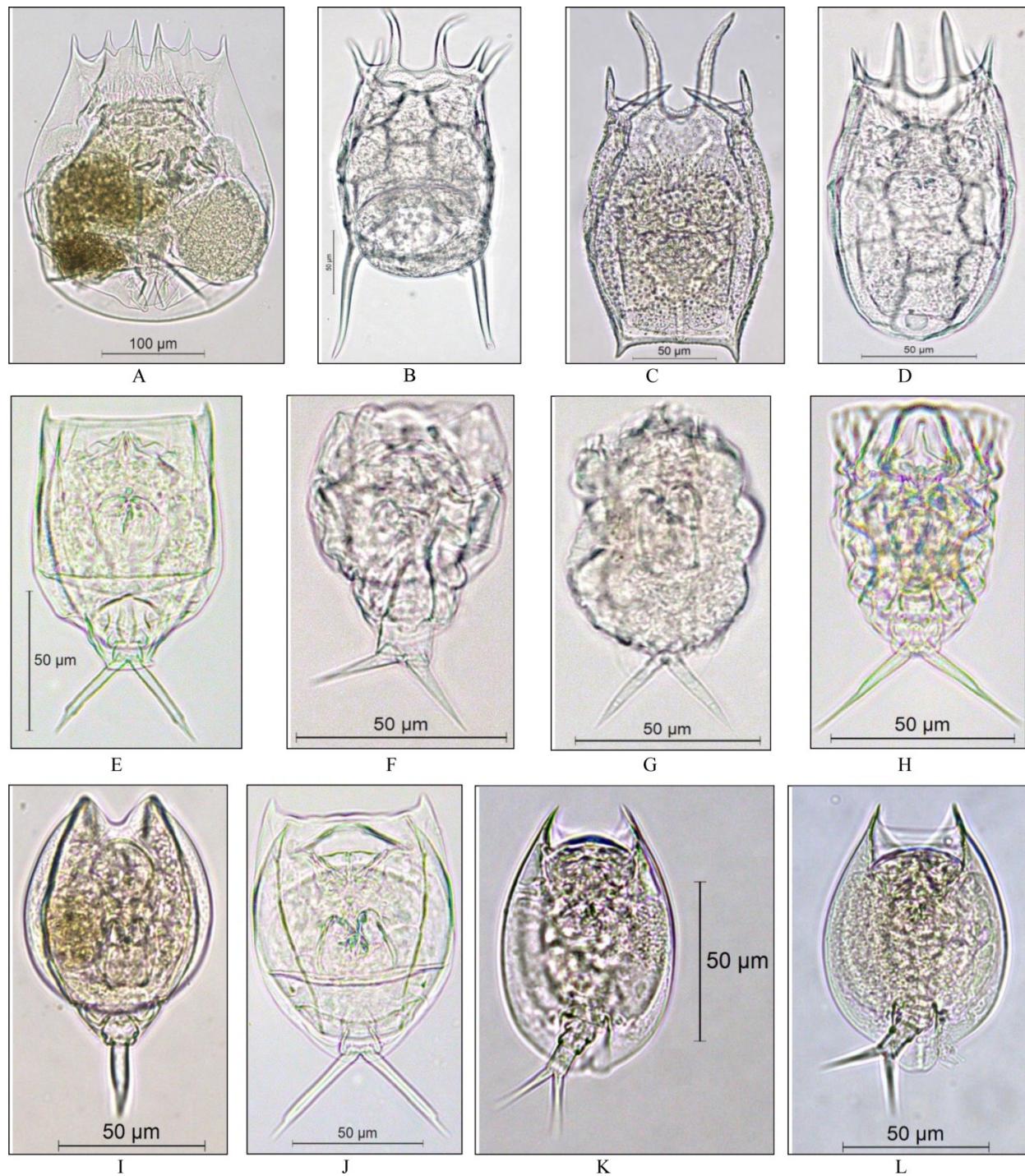


Figure 10. Interesting species. **A** = *Brachionus durgae* Dhanapathi (dorsal view); **B** = *Keratella hiemalis* Carlin (ventral view, Sharma & Sharma 2018a); **C** = *Keratella serrulata* (Ehrenberg) (dorsal view, Sharma & Sharma 2018a); **D** = *Keratella tictinensis* (Callerio) (ventral view, Sharma and Sharma 2018a); **E** = *Lecane bifastigata* Hauer, (dorsal view); **F** = *Lecane calcaria* Harring & Myers (ventral view); **G** = *Lecane clara* (Bryce) (dorsal view); **H** = *Lecane dorysimilis* Trinh Dang, Segers & Sanoamuang (ventral view); **I** = *Lecane marchantaria* Koste & Robertson (dorsal view, Sharma & Sharma 2019a); **J** = *Lecane rhenana* Hauer (ventral view); **K** = *Lepadella desmeti* Segers & Chittapun (ventral view, Sharma & Sharma 2015a); **L** = *Lepadella neglecta* Segers & Dumont (ventral view, Sharma & Sharma 2018c).

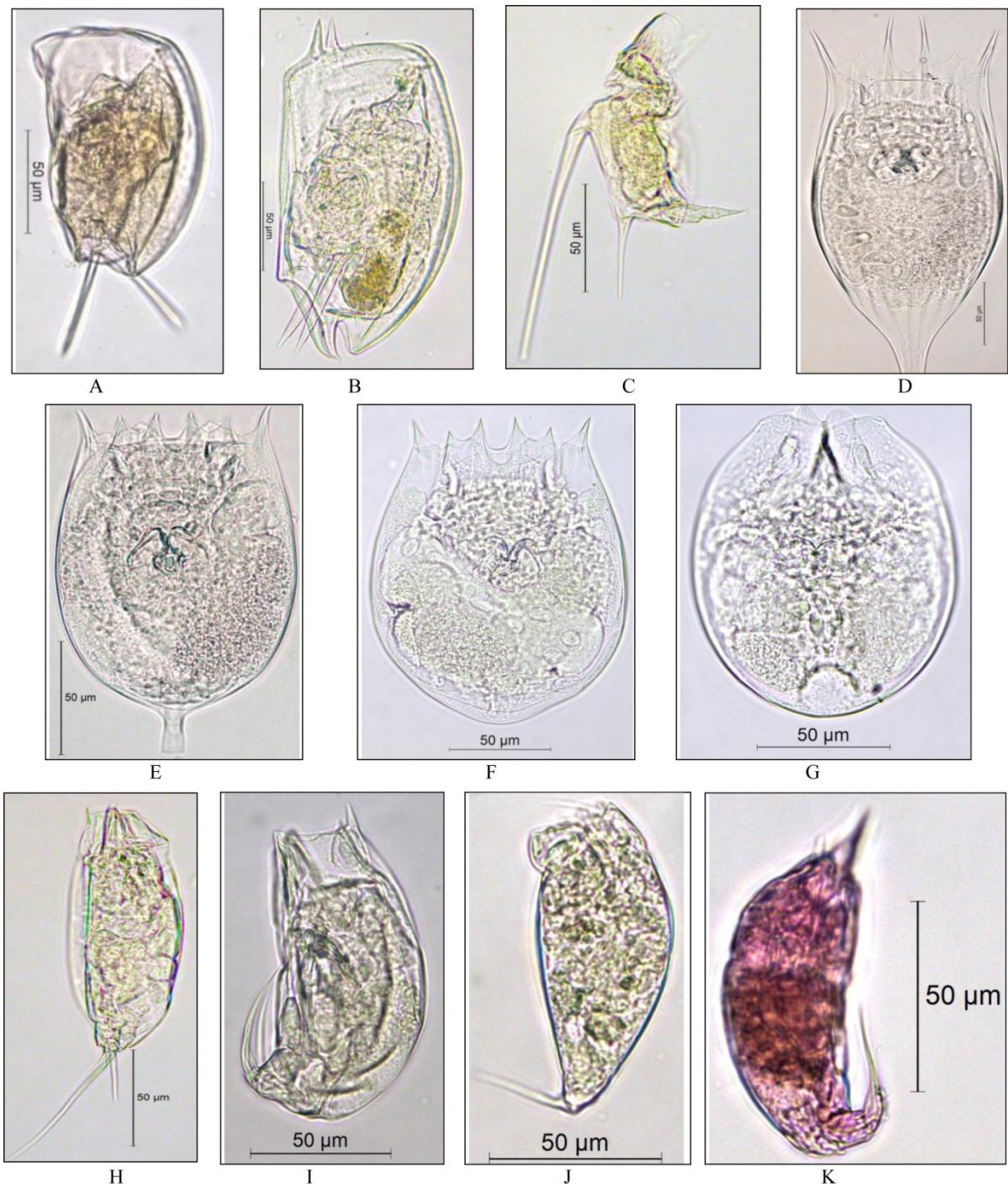


Figure 11. Interesting Rotifera. **A** = *Mytilina lobata* Pourriot (lateral view, Sharma & Sharma 2019b); **B** = *Mytilina michelangellii* Reid & Turner (lateral view); **C** = *Squatinella bifurca* (Bolton) (lateral view, Sharma et al. 2017); **D** = *Notholca acuminata* (Ehrenberg) (ventral view, Sharma & Sharma 2018c); **E** = *Notholca labis* Gosse (ventral view, Sharma & Sharma 2018c); **F** = *Notholca squamula* (Muller) (ventral view); **G** = *Testudinella insinuata* Hauer (ventral view, Sharma and Sharma, 2018b); **H** = *Trichocerca edmondsoni* (Myers) (lateral view); **I** = *Trichocerca maior* Hauer (lateral view); **J** = *Trichocerca siamensis* Segers & Pholpunthin (lateral view, Sharma & Sharma, 2015a); **K** = *Trichocerca taurocephala* (Hauer) (lateral view, after Sharma & Sharma 2015a).

Indian Rotifera includes 11 Australasian, 15 Oriental, 20 Paleotropical, 15 Indian endemics, 10 Holarctic and four Palearctic species, one species each of the Indo-Chinese and Cosmo (sub) tropical categories, eight cold-water species and 16 other interesting species (Figs. 5–11). A total of 176 species depict regional distribution interest in India; of these, 70 species are known for their

distribution restricted to NEI India. The rotifer diversity in Ramsar sites, floodplain lakes of Assam (*beels*) and Manipur (*pats*) and small floodplain wetlands (*dobas* or *dubies*) and small lentic biotopes of NEI; the floodplain wetlands of Kashmir and West Bengal; and small lentic environs of the Gangetic and north Bengal regions of West Bengal are included in Table 2.

Table 2: Rotifera richness in various aquatic ecosystems (Modified after Sharma & Sharma 2019b)

Study sites↓	Taxa →	Species	Genera	Families
NORTHEAST INDIA				
Ramsar sites				
Loktak Lake, Manipur (93° 46'–93° 55'E, 24° 25'–24° 42'N)	203	48	23	
Deepor Beel, Assam (91° 35'–91° 43'E, 26° 05'–26° 11'N)	183	36	20	
Floodplain lakes (<i>beels</i>) of Brahmaputra Basin, Assam	244	46	21	
Barpeta (6 <i>beels</i>) (90° 52'–91° 42'E, 26° 17'–26° 40'N)	176	35	19	
Majuli River Island (10 <i>beels</i>) (93°–95° E, 25°–27° N)	174	34	18	
Dibrus-Saikhowa Biosphere Reserve (5 <i>beels</i>) (95°22'–95°24'E, 27°34'–27°55'N)	162	32	18	
Tinsukia (5 <i>beels</i>) (95°22'–96°35'E, 27°14'–28°40'N)	169	33	19	
Dibrugarh (6 <i>beels</i>) (93°22'–95°35'E, 26°19'–27°30'N)	179	35	19	
Floodplain lakes (<i>pats</i>) of Manipur				
Manipur valley (15 <i>pats</i>) (93°45'–94°00'E, 24°25'–24°45'N)	218	48	23	
Small floodplain wetlands (<i>dobas</i> or <i>dubies</i>) of Assam				
Brahmaputra valley (90°–93°E; 26°–27° N)	167	34	18	
Lower Assam	154	34	18	
Central Assam	150	31	19	
Upper Assam	135	30	17	
Barak valley (92°45'–92.75°E, 24°48'–24.80°N)	159	35	19	
NEI: small lentic ecosystems				
Arunachal Pradesh (91°20'–97°30'E, 26°28'–29°30'N)	165	37	19	
Nagaland (93°3'–93°5'E, 25°4'–27°0'N)	150	37	19	
Mizoram (92°15'–93°29'E, 21°58'–24°35'N)	162	35	19	
Meghalaya (90°05'–92°40'E, 25°10'–26°15'N)	161	40	20	
Tripura (92°10'–92°20'E, 22°56'–24°32'N)	163	35	19	
Manipur (93°50'–94°00'E, 24°10'–24°55'N)	169	44	22	
Meghalaya: small urban wetland	90	29	15	
OTHERS PARTS OF INDIA				
Floodplain wetlands of Kashmir valley	140	43	22	
Floodplain wetlands of West Bengal	152	40	19	
Small lentic ecosystems of Gangetic West Bengal	142	38	18	
Small lentic ecosystems of north Bengal	130	40	18	

DISCUSSION

We record a total of 434 valid species belonging to 68 genera and 25 families; these comprise ~82% and ~24% of the species of the phylum known from the Oriental region and globally (*vide* Segers 2008), respectively, and thus reveal the rich and diverse Rotifera assemblage of India. The Indian fauna is more speciose than the faunas of Thailand (Sa-Ardrit *et al.* 2013), Cambodia (Sor *et al.* 2015), Vietnam (Trinh *et al.* 2019), and Malaysia (Segers 2004, Fontaneto & Ricci 2004) from SE Asia, and is distinctly diverse than the fauna of Sri Lanka (Fernando 1980) – the sole reasonably studied country of south Asia. The comparisons characterize the Indian Rotifera to be most biodiverse *vis-a-vis* south and SE Asia faunas. Besides, a total of 359 species belonging to 25 families and 67 genera observed in our plankton and semi-planktonic collections from various regions comprise ~81%, ~88% and 96% of species, genera and families, respectively known from this country and thus reiterate important contributions of our studies to the rotifer fauna of India. In general, the Indian faunal surveys lacked focus on biodiversity till the end of the 20th century, while it received attention in limited subsequent works to-date. Nevertheless, the significant increase in the tally of rotifers species known from India, than the earlier reports (Sharma & Michael 1980, Sharma 1991, 1996, 1998a, Sharma & Sharma 2005), is attributed notably to our studies from NEI (Sharma 2004, 2005, 2014, Sharma & Sharma 2012, 2014a, 2014b, 2014c, 2015a, 2015b, 2015c, 2018a, 2018b, 2019a, 2019b, 2019c, 2019d, Sharma *et al.* 2016, 2017) and Jammu & Kashmir (Sharma & Sharma 2018a), and elsewhere from Madhya Pradesh (Sharma & Naik 1996), Tamil Nadu (Sharma & Sharma 2009) and West Bengal (Sharma 1998b).

Lecanidae (21.5, 27.9%) > Brachionidae (11.8, 15.4%) > Lepadellidae (10.4, 13.5%) contribute notably to the rotifer and monogonont species known to-date from India, respectively; the three families collectively comprise an important fraction (~44%) of the Indian Rotifera. In addition,

Trichocercidae > Notommatidae > Philodinidae include ~22% species, while Floscularidae > Testudinellidae > Euchlanidae > Synchaetidae = Trochophphaeridae indicate limited importance (~14%). The significance of the stated families imparts the ‘littoral-periphytic’ character to the Indian Rotifera broadly concurrent with the reports from Thailand (Sa-Ardrit *et al.* 2013), Cambodia (Sor *et al.* 2015) and Vietnam (Trinh *et al.* 2019). This generalization is further supported by inadequate documentation of the bdelloid and sessile rotifers from India till-date. The latitudinal variations of Rotifera vs. biogeographic role of the ‘tropic’ or ‘temperate’ centered taxa had been discussed by Green (1972), Pejler (1977), De Ridder (1981), Dumont (1983) and Segers (1996, 2001). We extend these remarks to the Indian rotifers *vides* the diverse nature of Lecanidae, Brachionidae and Lepadellidae, the speciose nature of the ‘tropic-centered’ *Lecane*, *Lepadella* and *Brachionus* (Sharma & Sharma 2017, 2019b) and also to certain extent that of ‘Laurasian’ centered *Trichocerca*. These features along with the predominance of cosmopolitan species and the reports of several pantropical and cosmotropical species impart a broadly ‘tropical character’ to the Indian Rotifera in agreement with the reports of Fernando (1980), Dussart *et al.* (1984), Segers (1996, 2001, 2008) and Green (2003). On the contrary, the localized valid reports of cold-water species of ‘temperate’ centered *Kellicottia*, *Keratella*, *Synchaeta* and *Notholca* from the sub-Himalayan and Himalayan latitudes of India are diagnostic of specific ecological regimes. We caution on emphasis of ‘cosmopolitan species’ importance as ‘cosmopolitanism’ concept is debated in certain freshwater zooplankton groups *vides* the integrative taxonomical approaches.

Rotifera of India is characterized by a notable fraction (~25%) of species of the global biogeography interest; these are assigned to the following categories:

Australasian: *Brachionus dichotomus reductus*, *B. falcatus reductus*, *B. kostei*, *B. lyratus*, *Macrochaetus danneelae*, *Lecane batillifer*, *L. shieli*, *L. sinuata*, *Notommata spinata*, *Testudinella walkeri*, and *Philodina squamosa*;

Oriental: *Brachionus donneri*, *B. murphyi*, *B. srisumonae*, *Colurella sanoamuangae*, *Filinia camasecla*, *Keratella edmondsoni*, *Lecane acanthinula*, *L. blachei*, *L. bulla diabolica*, *L. isanensis*, *L. latissima*, *L. niwati*, *L. solfatara*, *L. superaculeata*, and *Ptygura stephanion*;

Paleotropical: *Keratella javana*, *Dipleuchlanis ornata*, *Euchlanis semicarinata*, *Lepadella bicornis*, *L. discoidea*, *L. minoruoides*, *L. vandenbrandei*, *Lecane braumi*, *L. eswari*, *L. lateralis*, *L. simonneae*, *L. stichoclysta*, *L. unguiculata*, *Polyarthra indica*, *Testudinella brevicaudata*, *T. greeni*, *Trichocerca abilioi*, *T. braziensis*, *T. hollaerti*, and *T. kostei*;

Indian endemics: *Asplanchnopus bhimavaramensis*, *Collotheca hexalobata*, *C. tetralobata*, *Lecane jaintiaensis*, *L. schraederi*, *L. pawlowski*, *L. vasishti*, *Lepadella kostei*, *L. nartiangensis*, *Platyias quadricornis andhraensis*, *Proales indirae*, *Pseudoeuchlanis longipedes*, *Rotaria ovata*, *Testudinella* sp., and *T. sp. 1* (undetermined vide Sharma & Sharma 2018b);

Holarctic: *Lecane depressa*, *L. elasma*, *L. elongata*, *L. galeata*, *L. levistyla*, *L. stokesii*), *L. styrax*, *L. tryprema*, *Trichocerca taurcephala*, and *T. uncinata*;

Palearctic: *Encentrum longipes*, *Cephalodella trigona*, *Lecane bifastigata*, and *Squatinella bifurca*;

Indo-Chinese: *Lecane dorysimilis*;

Cosmo (sub) tropical: *Brachionus durgae*;

Cold-water: *Hexarthra bulgarica*, *Keratella hiemalis*, *K. serrulata*, *Kellicottia longispina*, *Notholca acuminata*, *N. labis*, *N. squamula*, and *N. striata*,

Others: *Lecane calcaria*, *L. ligona*, *L. marchantaria*, *L. rhenana*, *L. ruttneri*, *L. rugosa*, *L. sola*, *Lepadella desmeti*, *L. patella oblonga*, *L. neglecta*, *Mytilina lobata*, *M. michelangellii*, *Ptygura tacita*, *Testudinella amphora*, *Trichocerca edmondsoni*, and *T. siamensis*.

The reports of the Australasian rotifers, known exclusively from south and SE Asia and Australia, highlight affinity of the Indian Rotifera with Southeast Asian and Australian faunas. The Oriental rotifers reiterate affinity with south and Southeast Asia faunas, and the richness of Pale-

otropical species is noteworthy. Interestingly, the reports of ~91%, ~93% and ~90% species of the three categories from NEI (Sharma & Sharma 2019b) in particular reveal a closer faunal affinity of the rotifer assemblages of this region with the SE Asian and Australian faunas, and thus assign a distinctive biogeographic identity to NEI Rotifera in contrast with the rest of India. This salient feature is hypothesized as an incursion of various SE Asian and Australian rotifers through 'the Assam gateway' – a unique biogeographic corridor of India (Sharma & Sharma 2019b). Besides, Indian Rotifera reveals ~41% species of regional biogeography interest. Of these, *Adineta vaga major*, *A. longicornis*, *Cephalodella intuta*, *C. ventripes*, *Colurella tesselata*, *Habrotrocha angusticollis*, *H. angusticollis attenuata*, *H. lata*, *H. leitgebii*, *H. microcephala*, *Keratella javana*, *Lecane aeganea*, *L. clara*, *L. glypta*, *L. rhytida*, *L. stichaea*, *Lepadella heterodactyla*, *L. latusinus*, *L. patella oblonga*, *Monommata grandis*, *M. maculata*, *Stephanoceros fimbriatus*, *Taphrocampa annulosa*, *Testudinella dendradena*, *T. tridentata*, *Trichocerca bidens*, *T. insignis*, *T. insulana*, *T. mus*, *T. scipio*, and *T. sulcata* are known to-date for their distribution restricted to NEI (Sharma & Sharma 2019b). *Cephalodella panarista*, *Dicranophorus myriophylli*, *Floscularia conifera*, *Hexarthra bulgarica*, *Itura aurita*, *Kellicottia longispina*, *Keratella hiemalis*, *Lecane elasma*, *Notholca striata*, *Notommata aurita*, *N. copeus*, *N. tripus*, *Synchaeta stylata*, *S. tremula*, *Testudinella insinuata*, *T. mucronata*, *Trichocerca cavia*, *Trichotria pocillum*, and *Trochosphaera solstitialis* are known exclusively from Jammu & Kashmir (Sharma & Sharma 2018a), while *Colurella colurus*, *Euchlanis meneta*, *Keratella serrulata*, *K. tictinensis*, *Mytilina michelangellii*, *Notholca acuminata*, *N. labis*, and *N. squamula* indicate validated reports restricted to both the Kashmir Himalayas and NEI (Sharma & Sharma 2018a, 2019b). In addition, *Ascomorpha saltans indica*, *Cephalodella megalocephalia*, *C. misgurnus*, *Lophocharis naias*, *Lepadella kostei*, *Lecane galeata*, *L. pawlowskii*, *L. perplexa*, *L. schraederi*, *Notommata pseudocerberus*, *Proales indirae* and *Ptygura furcillata* are reported only from the state of Gujarat (Wulfert 1966). Our

remarks thus highlight both the global and regional biogeographic interest of the Indian Rotifera even though more interesting species of the two categories are likely to be added pending analyses of extensive collections from hitherto unexplored regions of India and the 'Himalayan, Indo-Burmese and Western Ghats biodiversity hot-spots' in particular.

We consider the current paucity of the Indian endemics to be secondary as: (a) 10 rotifer species *i.e.* *Brachionus srisumonae*, *Colurella sanoamangae*, *Lecane dorysimilis*, *L. isanensis*, *L. latisimma*, *L. niwati*, *L. shieli*, *L. superaculeata*, *Lepadella desmeti* and *Trichocerca siamensis* added as new records from India (Sharma & Sharma 2019b) are originally described as new species from SE Asia; (b) a number of newer taxa observed in our collections from NEI yet await descriptions; (c) the paucity of endemics elsewhere from India is attributed to inadequate sampling particularly of diverse aquatic and semi-aquatic environs; and (d) the future collections from the 'Himalayan and Western Ghats biodiversity hot-spots' along with other unexplored / under-explored regions of India are likely to improve the status of the Indian endemics. The reports of the tropical-latitude populations of the Holarctic and Palaearctic species and other cold-water elements from the Himalayas are likely to represent glacial relicts as hypothesized by Segers (1996), while the reports of certain species in our sub-tropical collections are attributed to extension of the Himalayan mountain ranges as hypothesized by Sharma & Sharma (2014c).

Sharma (1991, 1996, 1998a) focussed attention on state-wise / regional biodiversity disparities. This lacuna still holds valid (Sharma & Sharma 2017) as highlighted by the fact that amongst 29 states of India, the rotifer assemblages of only 10 states are reasonably well examined, while the regional diversity studies evade attention except for NEI. Referring to NEI, it reveals a total of 303 species (Sharma & Sharma 2019b), while its seven states namely Assam > Manipur > Tripura, Arunachal Pradesh > Mizoram \geq Meghalaya > Nagaland record 244, 200, 176, 172, 162, 161 and

150 species, respectively. NEI fauna as thus far characterized categorizes it as the most Rotifera biodiverse region of India and also interestingly as one of the most biodiverse in comparison with the countries of south and SE Asia. These salient features are hypothesized to habitat heterogeneity of water bodies located under diverse geo-ecological regimes of NEI, location of this region under the 'Himalayan' and the 'Indo-Burmese' biodiversity hotspots, 'the Assam gateway' – an interesting biogeographic corridor of India and the sampling intensity (Sharma & Sharma 2019b), and overall the 'Rotiferologist effect' (Fontaneto *et al.* 2012). In light of our earlier meta-diversity updates on NEI (Sharma & Sharma 2005, 2014a, 2019b), we expect more diverse rotifer assemblage of this region pending analyses of the extensive collections from practically unexplored eastern Himalayan state of Sikkim (except for the report of Murray 1906) as well as under-explored eastern Himalayan state of Arunachal Pradesh (Sharma and Sharma 2019a). We also extend our remarks on regional / state wise biodiversity disparities to the states of western India; of these, Jammu & Kashmir Rotifera records 173 species (Sharma and Sharma 2018a) and offers scope of the future update, and Uttarakhand Rotifera (Sharma 2021) is poorly documented, while Himachal Pradesh and Ladakh yet lack biodiversity surveys on the taxon (BKS, unpublished). Further, we report 177 and 168 species from the states of Tamil Nadu (Sharma & Sharma 2009) and West Bengal (Sharma 1998b) of east and south India respectively. Our recent studies (BKS unpublished) recording 104 species from Bihar (eastern India); 149, 109 and 64 species from Maharashtra, Madhya Pradesh and Goa, respectively from central India; and 146, 131, 108 and 141 species from Andhra Pradesh, Telengana, Kerala and Karnataka, respectively of south India attempt to augment the regional diversity status but yet suffer from the sampling intensity. Regional disparities of Rotifera biodiversity are influenced by spatial heterogeneity of the speciose monogonont families namely Lecanidae (Sharma & Sharma 2014b), Brachionidae (Sharma & Sharma 2014c), Lepadellidae (Sharma & Sharma 2015b) and Trichocercidae (BKS unpublished). However, we

focus special attention on paucity of Bdelloidea which are documented to-date *vide* the limited surveys by Anderson (1889), Murray (1906) and Edmondson & Hutchinson (1934) and thus deserve specific investigations in the future Rotifera studies from India.

Various Rotifera species examined from India are reported to exhibit morphological variations (Sharma 1983, Sharma and Sharma 2014b, 2014c, 2015a, 2015b, 2018a, 2018c, 2019a). The variations observed in *Brachionus angularis*, *B. bidentatus*, *B. caudatus*, *B. calyciflorus*, *B. diversicornis*, *B. falcatus*, *B. forficula*, *B. plicatilis*, *B. quadridentatus*, *Colurella colurus*, *C. obtusa*, *C. uncinata*, *Epiphantes brachionus*, *Euchlanis dilatata*, *Filinia longiseta*, *F. terminalis*, *Floscularia ringens*, *Keratella cochlearis*, *K. tropica*, *Lecane bulla*, *L. closterocerca*, *L. cornuta*, *L. curvicornis*, *L. hamata*, *L. inermis*, *L. leontina*, *L. luna*, *L. lunaris*, *L. ludwigii*, *L. monostyla*, *L. obtusa*, *L. quadridentata*, *L. signifera*, *L. stenroosi*, *L. unguilata*, *L. unguitata*, *Lepadella acuminata*, *L. costatoides*, *L. ovalis*, *L. patella*, *L. rhomboides*, *L. triptera*, *Limnias ceratophylli*, *Plationus patulus*, *Testudinella amphora*, *T. emarginula*, *T. patina*, *T. tridentata*, *Trichocerca rutilus* and *T. similis* thus await cryptic diversity analyses following some interesting studies (Suatoni *et al.* 2006; Schröder & Walsh 2010, Montero-Pau *et al.* 2011, Mills *et al.* 2017, Michaloudi *et al.* 2018) and using ‘integrative taxonomic approaches’ including ‘reverse taxonomy’ (Michaloudi *et al.* 2018). The specific focus on the likely cryptic species complexes is expected to enhance the faunal diversity status of Indian Rotifera.

The rotifer faunal diversity works from India are largely biased to the assemblages from the inland waters of the Indian mainland. In contrast, our exclusive report of 120 species from freshwater rotifers from the south Andaman (Sharma 2017, Sharma *et al.* 2017) highlights scope of extending such studies to insular freshwaters off other islands of the Andaman and Nicobar group of Islands and the Lakshadweep Islands. The rotifer diversity of the riverine systems is yet poorly known in spite of our highest report of 72 species, belonging to 30 genera and 17 families from an intensively sam-

pled 600 km long stretch of the river Narmada in Madhya Pradesh, Central India (Sharma & Naik 1996). We also focus attention on inadequately explored rotifer assemblages of the brackish water environs in light of the limited preliminary reports of Rama Rao & Chandra Mohan (1984), Anitha & George (2006), Varghese & Krishnan (2008), George *et al.* (2011), Varghese (2011), and Cleetus *et al.* (2015, 2016). The biodiversity literature, however, lacks the reports of marine rotifers from India.

Rotifera received attention of majority of ‘amateurs’ and fewer Indian ‘specialists’ to-date; the former invariably listed planktonic species from certain ponds, lakes and reservoirs. This trend has hampered holistic analyses of the rotifer assemblages, and the sessile, colonial and bdelloid species in particular, while the littoral-periphytic species are reported in selected studies (Sharma & Sharma 2017). Further, the Indian literature is loaded with works ‘poor illustrations’ or ‘micro-photographs’ which fail to enable an objective opinion on actual status of various recorded taxa and thus render them ‘unverifiable’ (Sharma & Sharma 2017), while lack of ‘voucher specimens’ categorize many other reports as ‘invalidated and unverifiable’. ‘Dubious reports’ of species of temperate-centered *Keratella*, *Kellicottia*, *Notholca* and *Synchaeta*, ‘unrealistic’ and ‘fuzzy’ reports of *Brachionus havanaensis* and *Keratella valga*, and ‘incomplete species lists’ due to ‘overlooking of identification of small species’ adversely influence the rotifer biodiversity studies. The ‘sloppy and uncritical’ descriptions of new taxa, another notable impediment, is highlighted by synonymized 15 new species and subspecies (Sharma & Sharma 2017), while nine new species are designated as ‘species inquirenda’ (Segers 2007), *Pseudoembata acutipoda* Wycliffe & Michael is treated as ‘Genus & species inquirendus’ (Segers 2007, Jersabek & Leitner 2013) and four species are categorized as ‘nomen nudum’ (Sharma & Sharma 2017). Above all, the majority of ‘classical taxonomy’ based faunal works highlight need to shift to ‘integrative taxonomic approaches’ for the effective biodiversity updates on Indian Rotifera.

Analyses of the rotifer diversity from diverse aquatic environs of India remained neglected until certain noteworthy inputs from the floodplains lakes (*beels* and *pats*) of NEI (Sharma & Sharma 2001, 2008, 2014a, 2014d, 2019b, Sharma 2005, 2009a, 2009b, 2014, unpublished) resulting in the reports of 244 species belonging to 46 genera and 21 families from the *beels* of Assam, and 210 species belonging to 48 genera and 23 families from *pats* of Manipur. We, hypothesize these biodiverse Rotifera assemblages to habitat diversity and environmental heterogeneity of the floodplain lakes of NEI located in the 'Indo-Burmese biodiversity hot-spot'. Further, Assam *beels* record more speciose rotifers and those of Manipur *pats* are marginally diverse than the reports of 207 (Segers *et al.* 1993) and 218 (Bonecker *et al.* 1998) species from the floodplains of Africa and South America, respectively. Our results endorse hypothesis of Segers *et al.* (1993) on the floodplain lakes as the globally important rotifer habitats. Besides, our collections affirm the fairly speciose Rotifera of the Kashmir valley (140 species: Sharma & Sharma 2018a) and West Bengal (152 species: BKS, unpublished) floodplains, while the floodplain lakes elsewhere from India are yet to adequately surveyed for Rotifera biodiversity.

Loktak Lake (Sharma & Sharma 2018c, 2019a, BKS unpublished) and Deepor Beel (Sharma & Sharma 2011, 2012, 2013, 2015c, BKS unpublished), only two intensively sampled Ramsar sites of India record 203 and 191 species respectively, and are thus categorized as the globally megadiverse Rotifera ecosystems. These important floodplain lakes of NEI depict biodiverse Rotifera than the Rio Pilcomayo National Park (114 species, Jose de Paggi 2001) and Thale-Noi Lake (106 species, Segers & Pholpunthin 1997) – the Ramsar sites of Argentina and Thailand, respectively as well as the well sampled Upper Paraná floodplain of Brazil (184 species; Bonecker *et al.* 2005). Our reports from Loktak Lake and Deepor Beel assume distinct national importance in contrast to the poor state-of-art status of the rotifer biodiversity of rest of 40 Ramsar sites of India (Chandra *et al.* 2021). The comparisons highlight

importance of extension of studies on Rotifera assemblages from other Ramsar sites of this country *vis-à-vis* potential to augment the biodiversity status of Indian fauna. Interestingly, our reports of 85 species each in December 2016 and January 2017 samples from Deepor beel and 86 and 89 species in November and December 2017 collections from Loktak Lake (Sharma & Sharma 2019b), and 84 and 81 species (during May and June, 2017) from a floodplain lake (*beel*) of upper Assam highlight speciose rotifer constellations per sample. We designate the speciose constellations of 80+ species per sample as the 'Rotifera paradox' as these depict examples of intriguing possibility of the co-existence of a number of species due to high amount of niche overlaps as hypothesized (MacArthur 1965).

The small water bodies (ponds and wetlands) are considered as keystone systems for analyses of biodiversity (Vad *et al.* 2017; Oertli 2018). Our collections from small floodplain wetlands (*dobas* or *dubies*) of the Brahmaputra and the Barak river basins of Assam state of NEI report 167 and 156 species, respectively and thus highlight the speciose rotifers. Besides, our reports of 165, 150, 162 and 161 species highlight species-rich rotifer assemblages of small lentic biotopes (wetlands) predominant in the hill states of Arunachal Pradesh, Nagaland, Mizoram and Meghalaya states of NEI, respectively (Sharma & Sharma 2019b), while 163 and 168 species known from small wetlands of Tripura and Manipur states of NEI, respectively also endorse our results. Hill *et al.* (2017) hypothesized the importance of small urban wetlands for maintaining regional biodiversity in highly modified urban environments. This hypothesis is affirmed by 90 species reported from a small urban wetland of Meghalaya state (Sharma & Sharma 2021). In general, the biodiversity importance of *dobas* or *dubies*, and other small and urban wetlands of NEI are attributed to habitat heterogeneity of these unstructured environs and the sampling intensity. Our collections from *dobas* or *dubies* of the Majuli River Island and those of upper Assam highlight 'Rotifera paradox' with the speciose assemblages of up to 50 species per sample (Sharma & Sharma

2019b, 2019c, 2019d). Besides, our report of 46 species per sample from small urban wetland of Meghalaya (Sharma & Sharma 2021) is categorized as ‘Rotifera paradox’ analogous to the reports (Sharma & Sharma, 2019b, 2019c, 2019b) from unstructured *dobas* or *dubies*.

To sum up, the rich and diverse Indian Rotifera highlights its biodiversity interest and notable fractions of species of the global and regional distribution interest impart biogeography importance. The rotifer fauna of India as thus far characterized reflects the littoral-periphytic nature and broadly tropical character though certain cold-water species are observed from the sub-Himalayan and Himalayan latitudes. We highlight the disparity of the state wise / regional biodiversity studies, inadequate analyses of bdelloid rotifers, and spatial heterogeneity of the richness. NEI is notable for the richest regional Rotifera diversity; Loktak Lake and Deepor beel deserve global attention as the rotifer megadiverse environs; and the floodplain lakes (*beels* and *pats*), the small floodplain wetlands (*dobas* or *dubies*) and small lentic environs depict the speciose assemblages with interesting instances of ‘Rotifera paradox’. The biodiversity status of Indian Rotifera yet needs to be augmented based on the intensive sampling of unexplored or under-explored states / regions / ecosystems, the ‘Himalayan and Western Ghats biodiversity hot-spots’, and various ‘Ramsar’ sites of India. Analyses of cryptic diversity as well as adequate focus on the sessile, colonial, benthic and littoral-periphytic assemblages, and identification of smaller species deserve attention. As per conservative estimate, we expect the Indian Rotifera tally of 550+ species pending attention to various lacunae.

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